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THE MICROBIOSTRATIGRAPHY OF THE PALAEOCENE OF THE NORTHWEST EUROPEAN CONTINENTAL SHELF

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Ph.D. 1995

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Michael D. Bidgood

The Microbiostratigraphy of the Palaeocene of the Northwest European Continental Shelf

by

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A thesis submitted to the University of Plymouth
in partial fulfilment for the degree of

DOCTOR OF PHILOSOPHY

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In collaboration with
Shell (U.K.) Exploration & Production Ltd.

September 1995

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Abstract

The Microbiostratigraphy of the Palaeocene of the
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A total of 186 samples taken from 9 offshore Central & Southern North Sea boreholes, 1 onshore UK borehole, 2 onshore UK localities and 2 onshore Danish localities were processed and analysed for microfauna. A total of 273 individual taxa were identified, the majority to species level. The dominant microfaunal group recorded are the Foraminifera of which 23 genera were agglutinated, 75 calcareous benthonic and 21 planktonic. Other groups recorded are the Ostracoda which comprised 5 genera, Diatomacea 2 and Radiolaria 1.

The recorded taxa are diagnosed and their stratigraphic and palaeoenvironmental significance discussed. The samples range in age from Late Cretaceous (Maastrichtian) through Palaeocene (Danian & Thanetian) to Early Eocene (Ypresian) and occasionally Middle Eocene (Lutetian). The offshore boreholes are biostratigraphically zoned with respect to the published biozonation scheme of King, 1989, and the so-called "bioevents" (i.e. microfossil marker horizons) described by Mudge & Copestake, 1992.

The emphasis of the study was placed on the stratigraphical distribution of the microfaunas, particularly in the offshore realm where the majority of the boreholes (7) are located in the Southern North Sea area (Quadrants 44 and 49); a region lacking in previously published research on microfaunas of this age. The biozonation scheme of King, 1989, is found to be broadly applicable to all of the boreholes studied although some differences in detail were noted. Not all of the bioevents of Mudge & Copestake (1992) are recorded. The samples studied are insufficiently closely spaced to permit the construction here of a separate biozonation scheme, specific to the Southern North Sea area, although it is considered that the future creation of such a scheme could be justified with additional data. A total of 53 individual microfossil marker horizons thought to have stratigraphic utility in the area are noted.

The bulk of the Palaeocene sediments deposited in the Southern North Sea area were laid down under moderate palaeodepths (c. middle shelf) and probably representative of the so-called "outer sublittoral" biofacies of King, 1983. Evidence for progressive deepening of water depth towards the north of the area and into the Silver Pit Basin was noted. The microfaunal assemblages from the offshore boreholes are similar in overall character to microfaunas recorded from onshore Palaeogene sections in the UK and Denmark.

List of Text Figures

Acknowledgements

It is impossible for someone who has taken the best part of twelve years to complete a thesis of this sort, not to have had the assistance of many friends and colleagues along the way. Firstly, I would like to thank my supervisor, Prof. Malcolm Hart, for his support, critiques, encouragement and above all, patience. Hope you've got room on your shelf for this one, Malcolm.

It is traditional to leave thanks for close family support until the end of this section. However, bearing in mind all the days and evenings I have been shut away completing this work, I cannot thank those around me enough for their tolerance and encouragement, particularly over the last two years. This deserves mention at the earliest opportunity. To all my family, particularly my wife Gill, and son Sam, thank you. This thesis would *never* have been finished without you.

I would also like to thank Shell (UK) Exploration & Production Ltd. who provided the bulk of the material studied in this work from released commercial North Sea wells. Thanks are extended to Dr. Paul Taueccio, Dr. Martin Broelsma and Dr. W. Sikkema. Also, thanks to the British Geological Survey who allowed the author to sample from the Wormingford Mere and Bures boreholes. Dr. Bill Glass of the University of Colorado is thanked for his spectral analysis of glassy spherules recorded in some samples.

I was ably assisted (and entertained!) in the Danish field by Dr. Bruce Tocher. The evenings in the bar in Arhus, Jutland, will remain indelibly etched on my memory if not his! Fieldwork in the southeast of England would not have been possible without the indestructible "Bod".

Financial support for this study was provided by a Research Studentship from the Natural Environment Research Council (N.E.R.C.). Additional funds were obtained through various part-time teaching opportunities funded by the University of Plymouth. To both organisations I give grateful thanks. Production costs for the thesis were met by Grampian Stratigraphic Services.

During the last dozen or so years, I have worked alongside many colleagues who have, directly or indirectly, contributed in some way to this research. However, I must state that I am solely responsible for the opinions and interpretations drawn in this thesis and any errors or omissions are my responsibility alone. I extend grateful thanks to Mr. John Abraham, Mr. David Bailey, Dr. Haydon Bailey, Mr. Hugh Balhatchett, Dr. Kim Ball, Mrs. Theresa Blank, Mr. Roger Bowers, Dr. Steve Crittenden, Mr. Wil Diver, Dr. Chris Dodd, Mr. Bob Downie, Ms. Julie Downie, Mrs. Marion Duncan, Mr. Stan Duxbury, Dr. Robin Dyer, Ms. Liza Evans, Mr. Gordon Forbes, Mrs. Joan Fowler, Ms. Gill Fowler, Mr. Nick Fryer, Mrs. Christine Fryer, Ms. Margaret Grimbley, Mr. Wil Harpur, Dr. Colin Harris, Dr. Martin Harvey, Prof. Jo Haynes, Dr. Nick Holmes, Dr. Gareth Jones, Dr. Dave Jutson, Mr. Matt Kaye, Mr. Andy King, Mr. Brian Lakey, Dr. Paul Leary, Mr. Pete Manley, Ms. Fiona Marcella, Mr. Pete Mears, Mr. Richard Milne, Dr. Roy Moate, Mr. Graham Mott, Dr. Steve Packer, Mr. Randall Penney, Dr. Rob Seago, Dr. Mike Simmons, Mrs. Julia Sinclair, Ms. Dawn Stark, Ms. Val Stewart, Mr. Hamish Strang, Ms. Caroline Taplin, Mr. Chris Thorne, Dr. Ian Tunbridge, Ms. Marianne Wamser, Prof. Robin Whatley and Dr. Colin Williams. I am particularly grateful to Ms. Sue McNaughton who generously provided a microscope during the final analytical phase of the work, when, for personal reasons, access to research facilities were extremely limited.

This thesis was composed and written using Microsoft's "Word for Windows" version 6.0 word-processing package. Thanks are extended to all the nerds involved in developing this piece of kit and making the job of producing a thesis so much (?)easier. Stratigraphic distribution charts for offshore wells and onshore boreholes were produced using the "StrataBugs" database system, developed by StrataData Ltd. and I am grateful to Dr. John Athersuch, Paul Britton and Hamish Strang of that company for allowing me to use this package.

Finally, this thesis is dedicated to my late parents, especially my mother who, when I was small, always wanted me "...to become a doctor".

The lift doors split open and disgorged a tired but happy Lister onto the habitation deck corridor. He'd spent the last two days and a night down in the technical library, then another morning liasing with Holly in the geology lab. In the last fifty-six hours he'd learned many things. He'd started off thinking that the structure and composition of planet crust and rock formations was incredibly boring. But now he was absolutely certain of it.

RED DWARF
Part II: "Alone in a Godless universe and out of Shake'n'Vac"
Rob Grant & Doug Naylor

Declaration

This is to certify that the work submitted in partial fulfilment for the Degree of Doctor of Philosophy under the title "Microbiostratigraphy of the Palaeocene of the Northwest European Continental Shelf" is the result of original work.

All authors and works consulted are fully acknowledged. No part of this work has been submitted for any other degree and is not concurrently submitted in candidature for any other degree.

This study was financed with the aid of a studentship from the Natural Environment Research Council, with additional funds and samples provided by Shell (U.K.) Exploration & Production Ltd., London.

Relevant scientific seminars and conferences were regularly attended at which work was occasionally presented; external institutions were visited for consultation purposes:

1984-86	Various visits to Shell UK Ltd., London to present interim results and discussion with Shell staff stratigraphers.
1984:	"Chalk of the North Sea": J.A.P.E.C. 5-day course held at Burlington House, London (Geological Society of London).
1985:	"Micropalaeontology of Carbonate Environments": 3-day meeting held at Plymouth Polytechnic. Poster presented.
1986:	"Micropalaeontology of Northwest Europe". 2-day annual conference of the British Micropalaeontological Society, Aberdeen University. Paper prepared and presented but not published.
1986:	2-day visit to the British Museum (Natural History) to examine pertinent foraminiferal collections.

Signed...
Date.................8/9/95.......................
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Signed...
Date...
Prof. Malcolm B. Hart (Supervisor)

1.Introduction

1.1.Introductory Remarks

The scientific study of microfossils as a whole, and foraminifera in particular, began in the 18th century, although foraminifera were fascinating people long before that. The abundant *Nummulites* of the Eocene in the Middle East for instance, were thought to be the lithified remains of lentils dropped by Egyptian slaves during the building of the Great Pyramids, so common are they in the building stones of those monuments.

The micropalaeontologists of two hundred years ago however, confined their studies to Recent material collected around the British Isles and those retrieved during the long voyages of research vessels such as "Challenger". The study of ancient fossil foraminifera was, however, largely a European institution although later great impetus was given by the 1st World War and the increased demand for petroleum and petroleum products.

However, it was nearly a quarter of a century before this when the Polish scientist, Josef Grzybowski made the first recorded observation of borehole muds for the specific purpose of searching for foraminifera. He was rewarded by the discovery of several tens of species but, under the misapprehension that these species were very long ranging, did not attach any biostratigraphic significance to his finds. Fortunately, subsequent studies on this group were to prove him wrong and the science of foraminiferal biostratigraphy has become an important tool in the geological sciences. Grzybowski's work does have some bearing on the present study in that the strata he examined contained sediments of Palaeocene age and many of the species he recorded are to be found herein (Grzybowski 1880, 1896, 1897 & 1901).

Emphasis in foraminiferal studies in the 20th century switched to the United States where a booming automobile industry was creating excessive demands on the petroleum resources of that country. Joseph A. Cushman seized upon the value of foraminifera and initiated (in 1925) his own research laboratories which published countless records of new species and their stratigraphic distributions.

Foraminifera are widely used as a correlative tool in the petroleum industry because of their small size and value as biostratigraphic indicators. Rotary drilling usually pulverises all but the smallest of fossils thus making traditional stratigraphic correlation (e.g. with ammonites or other macrofossils) impossible.

The discovery of hydrocarbon accumulations around the North Sea basin initiated one of the most intensive exploration programmes seen in the petroleum industry. Many of the U.K.'s major oilfields have reservoirs of Tertiary (mainly Palaeocene and Eocene) age including the U.K.'s first discovered oilfield, Montrose, and the giant Forties field. Many hundreds of wells have been drilled in the North Sea Basin since the mid 1960's and many thousands of samples have been recovered. In contrast, the amount of published research emanating from this material is relatively sparse which reflects the high importance of confidentiality placed on this data by the companies concerned.

The stratigraphic interval under study here is the Palaeocene (and its associated deposits), the oldest epoch of the Tertiary period. It is an important interval for several reasons; it is the most recent epoch to be added to the Standard Geological Column and hence has been the subject of intense scrutiny prior to its acceptance, the nature of which still attracts controversy. It marks the earliest period of clastic deposition in Northwest Europe (and in many place worldwide) after a prolonged, tectonically quiet period of Late Cretaceous carbonate buildup. It occurs immediately after one of the most abrupt periods of global biotic extinction to affect the planet; and sediments of this age contain important accumulations of hydrocarbons in the North Sea Basin, which, at the time of writing attract great interest amongst the major oil companies with the relatively recent discoveries of, amongst others, the Alba and Nelson fields.

In addition to the major oil fields, Palaeogene sands in the Viking Graben contain mainly gas accumulations (e.g. Frigg and Heimdal fields). The trap-styles associated with all these (mainly deep water sands) fields are numerous and varied and include salt-induced anticlines (Cod), drapes over deep-seated fault blocks (Forties & Montrose), differential compaction structures associated with stacked sand bodies (Frigg) and up-dip sand pinch-outs (Balder). Ultimate recoverable reserves in established Palaeocene / Early Eocene clastic reservoirs from the UK and Norwegian sectors are approximately 4.7 x 10^9 barrels of oil and 10 x 10^{12} scf gas (Ziegler, 1990).

Interest in the hydrocarbon potential of Palaeogene deposits has resulted in intensive studies of Northern and Central North Sea Palaeocene microfaunas by major oil companies and some of this data has been released for academic study and subsequent publication. However, in the southern part of the North Sea Basin, the Tertiary as a whole has attracted little industrial interest, as the primary target for petroleum exploration in this area has been and is, the largely Palaeozoic gas fields and associated coal deposits. Consequently, whilst published information on mainland European Palaeocene microfaunas is relatively good, the Southern North Sea area remains largely devoid of accessible data.

This thesis is therefore concerned with the study of the microfossils recovered from various Palaeocene localities around and under the North Sea, particularly south of latitude 58° North.

1.2.History of Previous Research

The first micropalaeontological study of the Palaeocene in the U.K. was made by Burrows & Holland (1897) who described 34 species of foraminifera from the Thanet Formation of Kent. Subsequently Haynes (1954, 1955, 1956, 1958a,b,c) and Wood & Haynes (1957) made comprehensive investigations and described a total of 132 species. Since then other workers (Haynes & El-Naggar, 1964; Barr & Berggren, 1964; Berggren, 1965; and El-Naggar, 1967) have commented mainly on the planktonic foraminifera and have noted problems in the dating of the Thanet Formation (see Chapter 7). Murray *et al.* (1981, 1989) reviewed the foraminiferal fauna for the whole of the U.K. onshore Palaeogene with an emphasis on its stratigraphic importance.

Due to the need for confidentiality, comparatively little literature on offshore (i.e. North Sea) Palaeocene microfaunas has emerged. Earliest records are from offshore Denmark (Rasmussen, 1974) and later, Gradstein & Berggren (1981) and Berggren & Gradstein (1981) investigated the agglutinated microfauna from several North Sea wells (mainly Norwegian and northern UK sectors). Charnock (1983 - unpubl. M.Sc. thesis) also described an agglutinating fauna of 57 species from an unnamed well in the Central North Sea, east of the Moray Firth. Subsequent papers include Gradstein *et al.* (1988), Jones (1988) and Gradstein & Kaminski (1989) deal with taxonomic and biostratigraphical issues. A recent taxonomic review of Palaeogene North Sea agglutinated foraminifera has been published by Charnock & Jones (1990), together with some updated biostratigraphic information.

Publications on the planktonic microfauna are even less common. Crittenden (1979 - unpubl. M.Sc. thesis, 1981, 1982, 1986) has described a Palaeocene planktonic fauna from well 49/24-2, just SE of the Indefatigable gas field (and one of the wells studied herein). He described a very diverse planktonic fauna of some 70 species which however, included taxa probably caved from higher stratigraphic levels (see Chapter 4 for a discussion on "caving"). Later workers have suggested that this may be somewhat overoptimistic (King, 1983, and this work). Copestake & Dyer (1981 - unpubl. report) recorded a Danian planktonic fauna (localities unmentioned) from the North Sea and noted some important index species.

King (1983) integrated results of planktonic and benthonic foraminifera and diatom and radiolaria data to produce a bipartite biostratigraphic scheme for the North Sea Tertiary based on planktonic ("NSP") and benthonic ("NSB") taxa. This was later revised (King, 1989) into a tripartite scheme with the addition of zonations based on agglutinating ("NSA") taxa.

The zonation of King (1983, 1989) has proved to be of great value and has been used as the basis of the stratigraphic framework for this study (see Chapter 7). .

Research on the microfaunas of the Palaeocene on the European and Scandinavian mainland has been plentiful and a full review is beyond the scope of this thesis, as is a review of the even more comprehensive literature of the Palaeocene worldwide. Many of the most important publications are listed below and some are discussed in subsequent chapters:

Denmark and Scandinavia:

Bang (1969, 1979); Berggren (1960a,b,c, 1961, 1962a,b, 1965a,b, 1967, 1968, 1977); Brönnimann (1952); Brotzen (1948); Hansen (1970); Hofker (1960a,b, 1962, 1966); Larsen & Jorgensen (1977); Reichel (1953); Surlyk & Birkelund (1982); Troelsen (1957) and Verdenius & Van Hinte (1983).

Northern and Central Europe (Benelux, Germany etc.):

Berggren (1967); Cepek & Moorkens (1979); Doppert (1980); Doppert & Neele (1983); Gartner & Hay (1962); Glaessner (1937); Grun (1969); Hofker (1960, 1961a, 1966, 1976); Hooybergs (1983); Moorkens (1969, 1971, 1972); Toxwenius (1983); Visser (1951) and Willems (1983).

Western Europe (France, Spain etc.):

Caro, Luterbacher *et al.* (1975); Costa, Denison & Downie (1978); Hay & Mohler (1967); Le Calvez (1970); Luterbacher (1984); Pomerol (1969, 1982);

Eastern Europe (including U.S.S.R.):

Berggren (1960b,c); Geroch (1959, 1960); Geroch & Nowak (1984); Grzybowski (1898 - English translation 1969); Jednorowska & Pozaryska (1983); Pokorny (1949, 1960); Morgeil & Olszewska (1981); Samuel & Simpson (1969) and Subbotina (1971).

Southern Europe (Italy, Mediterranean etc. incl. North Africa):

Aubert & Berggren (1976); Berggren & Aubert (1975); Bolli & Cita (1960); Cuvillier *et al.* (1955); Eliagoubi (1980); Haman & Haynes (1976); Hofker (1961b); Luterbacher (1964, 1975, 1984); Ten Dam & Sigal (1950) and Tromp (1949).

In this last section, the publication by Berggren & Aubert (1975) is particularly important and discusses the worldwide distribution of many of the benthonic foraminiferal species encountered in this project. Berggren & Aubert's results are summarised in Chapter 2.

1.3. Addendum

Wireline log depths are occasionally referred to in this thesis. The wireline logs themselves are, however, not included in this thesis.

2.North Sea Geological History

2.1.The Pre - Cretaceous

The geological evolution of the North Sea Basin is long and varied. A summary of the main events is given below but for more detailed treatments the reader is referred to Kent (1975), P. Ziegler (1975a, 1975b, 1977, 1978), W. Ziegler (1975), Woodland (1975), Illing and Hobson (1981) and Glennie (1990).

The earliest origins of the region can be traced back to the Precambrian Era, the cratonic blocks of which have remained essentially positive features throughout most of the Phanerozoic. During this early period (c. 1000 Mybp), the Caledonian Orogeny formed grabens in the Archean continent and marine sediments were deposited in the Iapetus Ocean (separating the Baltic and Laurentian plates) and the Tournquist Sea (separating the Baltic Shield from Greenland). In terms of present day continental position, Laurentia lay with its southern margin along the equator and contained what is now North America, Greenland and the northern part of the British Isles (Scotland, northern England and Northern Ireland). The Baltic Shield (Scandinavia and Eastern Europe) lay south of Laurentia's eastern margin at about 30-60° south with Iapetus separating the two. Gondwanaland (containing the remainder of the British Isles, Africa and the Austral continents) lay southwest of the Baltic Shield at latitudes greater than 60° south separated by the Tournquist Sea.

The Tournquist Sea had closed by the end of Ordovician times and corresponds to the present day suture marked by the North German-Polish Caledonides. Iapetus closed during Late Silurian times thereby uniting the British Isles. This closure was achieved by NW and SE directed subduction, the previous location of which is now marked by a weak suture traceable from the Shannon Estuary in Ireland, through the Solway Firth in Scotland and into the NE trending Northumberland Trough. As a result of these closures, a large supercontinent - Laurasia - was formed as were the major Caledonide (in Europe) and Appalachian (in America) mountain chains.

During Devonian times this "Old Red" continent shed vast quantities of material in widespread fluvial systems and also deposited sediments into the ocean known as "Proto-Tethys" to the south of the united Baltic Shields and Gondwanaland. In Late Devonian times, these Old Red Sandstones lay in a NW - SE trending depression between Scandinavia to the east and a combination of the Scottish Highlands and isolated positive areas around N. England, SE Ireland, Wales and SE England to the west. At this time, Proto-Tethys was closing bringing together Gondwanaland and Laurasia which would

shortly culminate in the Variscan Orogenic Belt, formed in Middle to Late Carboniferous times.

The Carboniferous period is economically important to the North Sea Basin as extensive deposits were laid down which subsequently converted to coal and, in turn, became important source rocks for most of the Southern North Sea and the Dutch-German-Polish gas fields, not to mention a significant economic resource in their own right. This coal deposition marked the change from the arid "Old Red" conditions of the southern deserts to more humid equatorial conditions as Laurasia migrated slowly northwards. Closure of Proto-Tethys resulted in a N-S compressive regime forming the Variscan Orogenic Belt traceable over the SE United States and Europe. In the Northwest European region, two conflicting structural regimes dominated:

1) A N-S compression resulted in the formation of two E-W trending basins, the Northern and Southern Permian Basins separated by the Mid-North Sea and Ringkøbing-Fyn Highs.

2) E-W tension resulted in the formation of a N-S system of grabens and half grabens cutting the two Permian Basins by the Central and Horn Grabens with corresponding northern extensions into the Viking and Oslo Grabens respectively.

Furthermore a series of E-W and SW-NE trending horsts and grabens occurred in the region to the south i.e. the English Channel, SW Approaches, Bristol Channel and Celtic Sea. Finally, Late Variscan E-W wrenching resulted in the early collapse of the Variscan Orogenic Belt in Europe.

The main elements of the geological and structural framework of the region at this time are shown in Text Figure 1. Some of the more pertinent structural elements are further shown together with study wells and localities in Text Figure 7.

In contrast to the history of the region so far, the subsequent structural evolution of NW Europe was greatly influenced by events which took place outside the North Sea area.

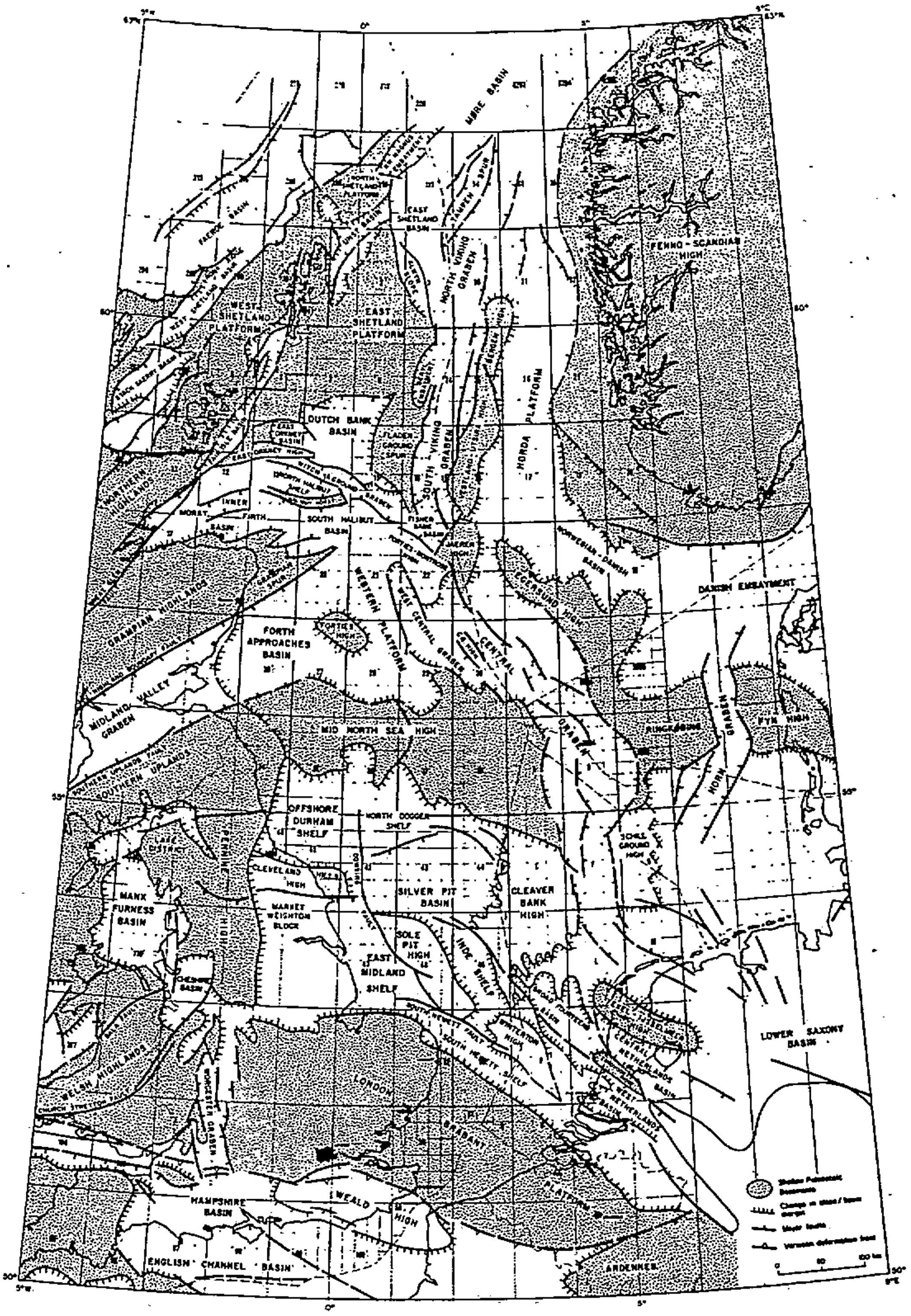
During Permian times, Laurasia re-crossed the desert latitudes of the northern hemisphere which resulted in another phase of red bed deposition (the New Red Sandstones). These fluvial and aeolian sandstones form important reservoir rocks and contain nearly all of the Southern North Sea gas reserves as well as significant oil reservoirs further north (e.g. the Auk and Argyll fields). Termed "Rotliegendes", these dune sandstones, larger than any present day dunes, testify to high velocity Permian winds attributed to a major period of

south-polar glaciation which resulted in larger polar high pressure areas which, in turn, concentrated the world's pressure belts around the equator (Glennie, 1983b). Below these reservoir sands lie early Permian volcanics, the origins of which are probably related to the earliest tensional movements associated with the creation of the aforementioned Permian Basins and North Sea graben systems. Following this and the period of sandstone deposition a major transgressive event occurred and covered the whole desert area. This "Zechstein Transgression" originated in an ocean somewhere beyond Greenland and Spitzbergen and waters invaded along a Proto-Atlantic and North Sea fracture system. Repeated evaporation of this dessert lake gave rise to thick salt sequences which in turn, provided a seal trapping migrating gas in the underlying Rotliegendes.

The Pangean supercontinent began to fragment during Triassic times beginning with rifting along the Proto-Atlantic and the westward extension of Tethys. It established a new structural framework in NW Europe resulting in a modification of the pattern inherited from the Permian by the superimposition of a graben system that was to control deposition throughout the remainder of the Mesozoic. These major new elements were the Viking - Central Grabens and the Central - Horn Grabens, north and south respectively of the Mid-North Sea and Ringkøbing-Fyn Highs which breached these positive structures. The Polish-Danish Trough was another rapidly subsiding feature accumulating a thick Triassic sequence. Triassic sediments in all the North Sea basins are dominantly red-beds of alluvial fan, fluvial, aeolian, sabkha, lacustrine and shallow marine origins.

The economically important Jurassic sediments were laid down in fault controlled basins and the complex system of grabens described above which were reactivated in the Jurassic. There was a general rise in sea level at this time and the first indications of halokinetic movements of Zechstein salts manifested themselves. The Atlantic Ocean continued to open and the old Permian sites of downwarp (the Central and Viking Grabens and the Moray Firth Basin) developed "grabenal" forms with evidence for crustal thinning in places within the grabens indicating that they were possibly aborted rifts related to the rise of a mantle plume in the Central North Sea Basin (Whiteman *et al.* 1975).

Text Figure 1 Structural Framework of Northwest Europe (after Glennie, 1990)



2.2.The Cretaceous

The tectonic setting during Cretaceous times was largely a continuation of that prevalent throughout the Jurassic. Positive features remained stable and the fault controlled basins subsided further and in some cases the rate of subsidence exceeded the rate of sediment supply leading to an overall increase in water depth. In some cases these Late "Kimmerian" movements took place along pre-existing fault lines (e.g. the Moray Firth Basin) but in others (e.g. the Viking Graben) there were new faults initiated outside the margins of the trough thus broadening the depositional basin. In addition, there was also large scale downwarping of basins accompanied by uplift of the margins. These major rifting phases have been correlated with sharp falls in sea level (Ziegler, 1978). To complicate matters, several areas of Jurassic deposition reversed the downward trend and were uplifted along elongated "inversion axes". Timing of these movements did not appear to relate to any particular pattern but was episodic in nature. In the Central Graben, inversion was complete before the end of Palaeocene times (Heybroek, 1975) whilst in other areas such as the Weald Basin of SE England, the inversion has been dated as Mid-Tertiary. The Sole-Pit inversion (east of the Humber Estuary) was a progressive event with uplift focus moving from the NE to the SW over a long period of time (Glennie, 1981).

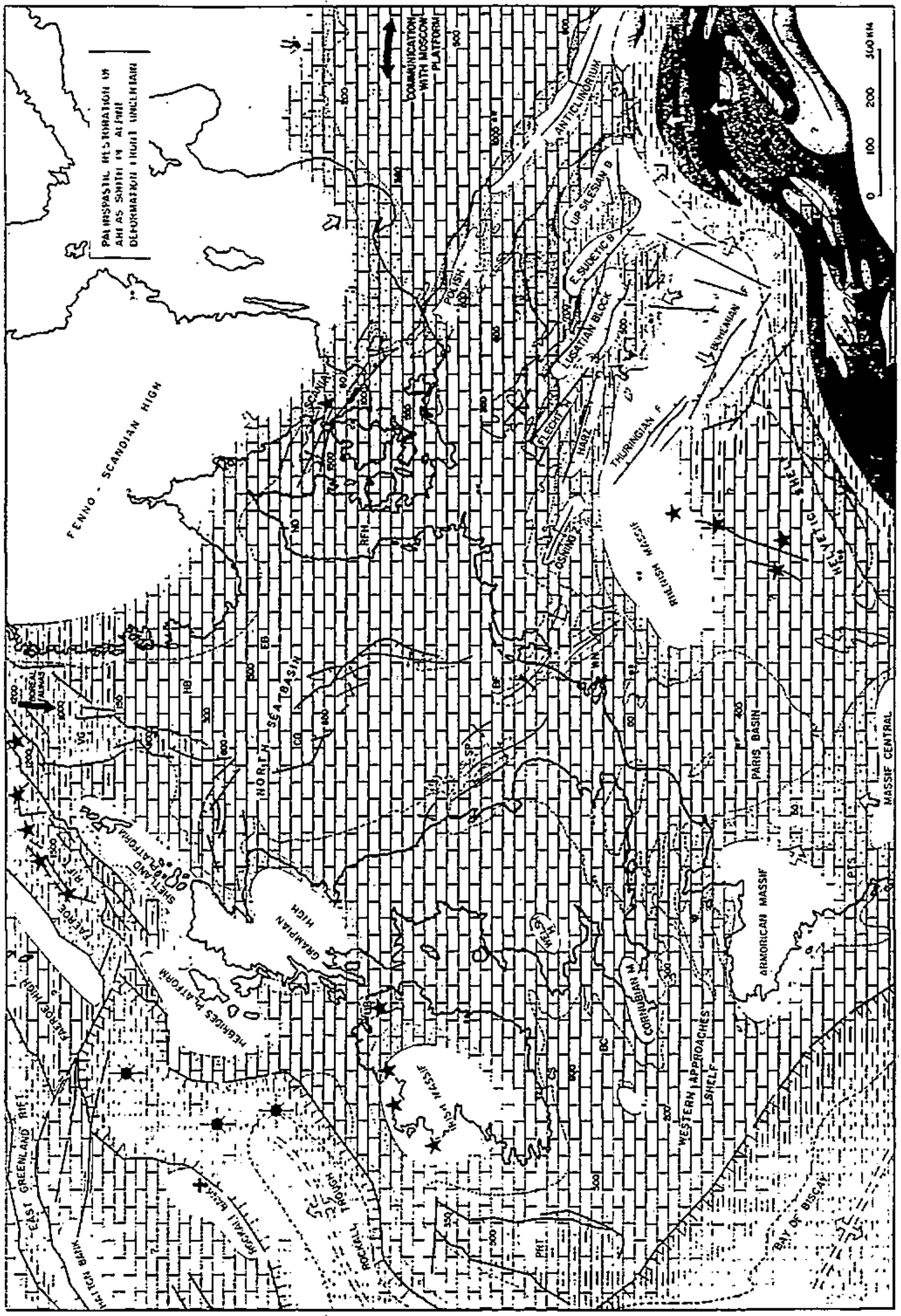
Generally, the Early Cretaceous marked a period of sea level rise when, in Aptian-Albian times, levels similar to the present were reached (Vail *et al.*, 1977; Hancock & Kauffman, 1979). During the earliest Cretaceous, the sea occupied only basinal regions and even in some of these cases (e.g. the Wealden) sediments were largely deposited under freshwater conditions. The North Sea region was to a large extent, cut off from the southern European Ocean (Tethys) with marine connections only through eastern (via Germany and Poland) and northern (via the Viking Graben into the early North Atlantic) passageways. The Late Aptian transgression breached the London - Brabbant Platform and more than doubled the size of the submerged area in the North Sea. Sea levels continued to rise during the remainder of the Cretaceous with most of the surrounding land becoming submerged by Campanian times. The little land that remained comprised the small islands of Norway, Scottish Highlands, parts of Wales and part of the Central Netherlands Inversion. Tectonism was largely absent at this times until the precursors of the Laramide disturbances began to appear in the Late Cretaceous (Ziegler, 1975).

As a result of the scarcity of land during Late Cretaceous times, there was very little clastic run-off from them into the surrounding seas. These quiet calm conditions enabled pelagic chalks to be laid down over most of the region in water depths ranging from 100 - 600 metres (Scholle, 1974; Kennedy & Garrison, 1975; Hancock, 1976) and possible reaching depths of up to 1000 metres in parts of the North Sea trenches (Hancock & Scholle, 1975). Towards the north of the region, Late Cretaceous siliciclastics (the Shetland Group) were deposited (Viking Graben) which probably originated from a Greenland source (Hancock & Scholle, 1975).

It was during Late Cretaceous times that the Laramide series of earth movements began. These structures are particularly strongly developed along the flanks of the Variscan complex and involved a reversal of the then dominant trend of right-lateral movements. Basins such as the Weald, previously open, were now squeezed and responded by inverting their basin centres. Areas affected by these movements included the Anglo-Dutch Basin, the complex anticlinal structures containing the major gas fields of this area being formed at this time. In the Central North sea, the Laramide phase was of lesser importance. There was renewed downwarping and downfaulting in the Central and south Viking Grabens and erosion removed large amounts of chalk over blocks near these margins. This material was redeposited in the deeper parts of the grabens forming the reservoirs for the Danian chalk fields (Dan, Ekofisk etc.). A generalised Late Cretaceous (including the Danian) palaeogeography is shown in Text Figure 2.

The whole interval from the Late Triassic to the end of the Cretaceous (and somewhat into the Early Tertiary) represented a period of aborted crustal separation between the continental plates of North America and Eurasia (Kent, 1975). Active rifting ceased during the Late Palaeocene when the final (and ultimately successful) separation became complete forming the Atlantic Ocean.

Text Figure 2 **Generalised Latest Cretaceous / Danian Palaeogeography (after Ziegler, 1990)**



Encl. 32. Senonian-Danian Palaeogeography (main sources: Császár et al., 1987; Dieter, 1967; Gwinner, 1971; Jaskowiak-Schoeneichowa, 1981; Klein et al., 1979; Ksiazkiewicz, 1960; Meyer, 1980; Sekiewski et al., 1976, Tröger, 1964)

2.3.The Palaeocene

During the earliest Tertiary, Greenland had not yet separated from Northwest Europe and the northernmost extension of the North Atlantic was situated over a spreading ridge which extended between the North American Plate and the Greenland-Rockall-Northwest European Plate to form the Labrador Sea (Laughton, 1972; Eldholm & Thiede, 1980). The Norwegian Sea between Northwest Europe and Greenland began to open in Early Tertiary times near magnetic anomaly 24-25 (60-63 Mybp on the Heirzler scale but revised by Premoli-Silva in a personal communication to Schrader *et al.* (1976) as 55 Mybp i.e. Early Eocene). Dating of plateau basalts from the Hebridean Volcanic Province and rare earth element studies confirmed this younger date (Schilling, 1976 and Kharin *et al.*, 1976). Volcanic eruptions from this region scattered ash-falls over a widespread area of Northwestern Europe and into the northeast Atlantic. They have been dated as occurring during part of Nannoplankton Zone NP10 (earliest Eocene) by correlation with DSDP cores from the Goban Spur (Knox, 1985). During the Late Palaeocene and Eocene this opening of the Norwegian Sea took place along the Reykjanes Ridge and was simultaneous with spreading in the Labrador Sea which ceased in the Middle Eocene. Spreading continued along the Reykjanes Ridge until the present day as Europe continues to separate from the Greenland-North American Plate (Laughton, 1972). Schilling (1976) suggests (from geochemical studies of basalts) that a broad and intense mantle upwelling in the area was the cause of continental separation and the development of oceanic crust. The effect of this Early Tertiary North Atlantic tectonic phase in the North Sea was significant as it probably had a major influence on the change of sedimentation styles from carbonate/pelagic to siliciclastic/terrigenous at the end of Danian times and thus had a marked effect on North Sea microfaunas at that time.

As shown above, the end of the Laramide phase marked the beginning of a period when the North Sea Basin underwent subsidence whilst ocean spreading centres became active in the North Atlantic. Sea levels fell worldwide and more land was exposed around the margins of the basin. Hence sedimentation throughout most of the Tertiary was dominated by "normal" intracratonic clastic styles with carbonate deposition lingering on only until earliest Tertiary (Danian) times in the more central parts of the basin and eastwards into the southern Scandinavian region and beyond. However, these later chalks (e.g. at Stevns Klint) tend to be preserved on structural "highs" as Bryozoan mounds. Palaeocene clastic sediments are mainly sands and shales with interbedded tuffs in the upper part of the Palaeocene. Water depths during the Tertiary were lower than those during the Late Cretaceous. However, a thick succession of deep water facies was deposited in the central parts of the basin indicating that these parts were subsiding more rapidly than those of the margins (Ziegler, 1975). Indeed, marginal areas may have undergone periods of interrupted deposition as most onshore Lower Tertiary sequences are incomplete and/or show rapid

changes in the environment of deposition (e.g. the Palaeogene of the Isle of Wight). These rapid sedimentation rates in the centre of the basin resulted in abnormally high pore fluid pressures ("overpressure") caused by the sediment not being able to de-water and compact fully on burial. This, fortunately, has resulted in hydrocarbons originally present in Palaeogene shales and clays being forced out and subsequently into the Danian and Maastrichtian chalk reservoirs of the Ekofisk field and the Palaeocene sands of the Forties province (Powers, 1967).

2.3.1.Early Palaeocene (Danian) Palaeogeography

Construction of an accurate Northwest European Danian palaeogeography is not easy. Danian strata are not common in onshore European localities and information from the North Sea Basin is limited. Many authors (including Ziegler, 1982, 1990) assimilate the Danian stage into the Late Cretaceous because of lithological similarities. Hence, Danian seas are often shown to have a larger extent than was probably the case (see Text Figure 2). Carbonate "chalks" of the Danian of Denmark and southern Scandinavia lack the totally pelagic aspects of the Late Cretaceous chalks and are composed predominantly of bryozoan bioherms with large-scale mound structures and cross-bedding, indicating deposition under shallower water conditions, though still below normal wave-base influence (Bromley, 1979). "Danian" (i.e. Montian and equivalent) sediments of France and the Benelux countries are more marginal and/or continental in aspect and this type of sedimentary style could well have extended into the southern reaches of the North Sea. Crittenden (1981), however, reports definite marine Danian strata containing planktonic foraminifera from well 49/24-2 although King (1983) later regarded the Danian sequence in this well as "anomalous" citing the general absence of Danian chalks in the area. Danian carbonate sediments have subsequently been proved over a large area of the North Sea (mainly Central North Sea) although they are absent north of the Shetland Isles (Mudge, 1979). Towards the north (in the Viking Graben), the carbonates pass laterally into clastic (though still very calcareous) sediments of the uppermost Shetland Group, Formation "F" (see Chapter 6.3). This lateral change probably shows that this area is near the minimum temperature limit for carbonate deposition and also that proximity to the Shetland Platform, probably one of the few emergent sediment source areas during the Late Cretaceous, promoted a normal shelf-clastic style of sediment accumulation.

Substantial amounts of uppermost Cretaceous strata and all of the Danian are missing from onshore U.K. localities indicating probable subaeriel exposure during or very soon after Danian times. Re-worked Danian and Late Cretaceous planktonic foraminifera have been recovered from the Thanet Formation of Kent by Haynes & El-Naggar (1964); (see also Barr & Berggren, 1965), and also in the London Clay on the Isle of Wight (Hart, *pers.*

comm.). Reworking of Danian and Late Cretaceous microfossils has also been recorded in Danian and younger sediments in many offshore wells (Mears *pers. comm.*). This is probably caused by gravity slumping of chalks along steep basin margins (i.e. the Central Graben).

The Danian North Sea Basin had a continuous marine connection with Tethys to the southeast along the Polish Trough and was probably connected through much of the time to the Atlantic via the English Channel (Curry, 1981). This allowed widespread distribution of a cosmopolitan planktonic foraminiferal fauna during that time. This widespread distribution allows fairly easy stratigraphic correlation of Northwest European Danian deposits with those of low-latitude regions e.g. Trinidad. The Danian sea was also open towards the north into a cold water Boreal sea - part of the present day Arctic Ocean. However, there was no communication with the North Atlantic as yet (see above).

In broad terms, the diversity of planktonic foraminifera reaches a maximum in tropical zones (and they are also abundant). In temperate zones diversity remains high although abundance decreases. Cool temperate and sub-polar zones show low diversity assemblages but very high (maximum) abundances (Bandy, 1964).

The planktonic microfaunas of the Danian North Sea Basin and surrounding areas (where present) are generally very simple in morphological aspect being of “globigerine” type or simple, small, thin-walled and unkeeled globorotaliids. Also they are seldom abundant and diverse. Bandy (1964) has indicated that the primary control of planktonic foraminiferal distribution in surfaces waters is temperature and salinity and suggests that during the Early Tertiary, the northernmost limit of globorotaliids, particularly keeled taxa, was to the south of the North Sea area. Keeled and thick-walled planktonic foraminiferal taxa are also strongly suggestive of the presence of relatively deep marine waters, the reproductive cycle of such taxa being associated with vertical migration to deeper waters. This suggests that Danian palaeoclimates were probably cool temperate at best and the Danian sea was comparatively shallow (c.<50m).

However, more important in this case to account for the lack of Danian “advanced” globorotaliid taxa, is the fact that only a few million years previously (at the end of the Cretaceous), the vast majority of the planktonic foraminifera (and indeed a substantial proportion of the world's life) was wiped out in a major extinction event. The theories for the cause(s) of this extinction event are almost as numerous as the number of fossil groups affected and are beyond the scope of this thesis. Clearly, however, only a few morphologically unspecialised (simple) taxa survived to cross the boundary, presumably because they, being simple, were least susceptible to the adverse environmental conditions that ?caused the extinctions. For the first few million years (i.e. the duration of the Danian)

more complex (i.e. non-keeled & keeled globorotaliid taxa) forms simply had not evolved. Even in tropical areas which are more conducive to highly diverse planktonic microfaunas, the precursors of Tertiary keeled planktonic taxa (e.g. *Morozovella praecursoria* (Morozova) / *M.angulata* (White)) did not appear until towards the end of the Danian. So-called "advanced", truly keeled species (e.g. *Morozovella acuta* (Toulmin) / *M.velascoensis* (Cushman)) did not appear until well into the Late Palaeocene.

Evidently, palaeoenvironmental interpretation using such a limited planktonic foraminiferal fauna as found in the Danian of the North Sea area alone is inadvisable. The lack of globorotaliid forms does not necessarily imply cool palaeotemperatures. Neither, therefore, does a lack of keeled taxa imply shallow palaeodepths although that may well have been the case.

Benthonic foraminiferal faunas from the same sediments, particularly offshore, are largely composed of calcareous types with taxa, at least at the genus level, very similar to those well established during the Late Cretaceous (e.g. *Gavelinella / Stensioeina*). They do not, in themselves, provided any detailed information regarding Danian palaeoenvironments save that they indicate bottom waters were well oxygenated.

Overall, the Early Palaeocene (Danian) of the North Sea area represented a tectonically quiescent period with shelf carbonate deposition and slumping along and within deeper basins. Several marine connections to areas outside the North Sea Basin allowed the development of a fairly cosmopolitan though simple planktonic foraminiferal fauna, limited in distribution only by temperature.

2.3.2.Late Palaeocene (Thanetian) Palaeogeography

After Danian times, sedimentation styles in the North Sea basin changed from largely carbonate to exclusively clastic and were to remain so until the present day. This major change of depositional style is related to tectonic events which occurred in the North Atlantic area rather than to influences from Alpine regions (Knox & Harland, 1979).

The U.K. during this time lay tucked between the main European and Greenland plates, along the eastern margin of the young North Atlantic. The northernmost arm of the Atlantic was undergoing active sea-floor spreading to the west of Greenland to form what is now the Labrador Sea (before switching to its present route between Europe/U.K. and Greenland in the latest Palaeocene / earliest Eocene). Regionally, the Palaeocene North Sea was connected, via a long N-S channel between Greenland and Fennoscandia, to an Arctic boreal ocean far to the North. There was also a shallower marine embayment into the

Polish Trough which had not yet fully connected with the Tethys southern ocean. The southwestern margin (present day English Channel) was also closed-off from the North Atlantic around the region along the Weald-Artois Ridge. The regional setting of the study area in the North Atlantic domain is shown in Text Figure 3 (after Zeigler, 1990).

During the Early Palaeogene, the region experienced several transgressive-regressive cycles (first described by Stamp, 1921) with Thanetian deposits being laid-down during the first of these. In the U.K. these consist of a basal pebble bed (Bullhead Conglomerate) of rolled flint pebbles overlain by marls (Pegwell Bay Marls) in turn overlain by silts and fine sands (the Reculver Silts). They contain a varied foraminiferal fauna including re-worked planktonics (Haynes, 1956-8). They are thought to have been deposited as a result of a transgression by a shallow sea from the east. This sea is though to have extended westwards to the Guildford area. No Thanetian deposits occur in the Hampshire Basin and it is likely that there was little or no connection between the Anglo-Paris Basin and the Atlantic at this time. Retreat of this sea, back towards the east during the later part of the Thanetian, laid-down the regressive non-marine (fluvio-deltaic) Reading and brackish, estuarine and marine Woolwich Beds, with the former grading eastwards of the London basin area into the later.

In Denmark, post-Danian Palaeocene sediments ("Selandian") are mainly marls (e.g. the Kerteminde Marl) and greensands. Similar sediments have also been found in Sweden (Brotzen, 1948).

In the Central and Northern North Sea areas, large thicknesses of Palaeocene sands (deltas, submarine fans and turbidites) have been found where they form important reservoirs for several large oilfields (Forties, Nelson, Everest, Montrose etc.). These sediments were shed off an emergent Shetland Platform in the Northern North Sea and Moray Firth, whilst other oilfields in the Norwegian sector (e.g. Frigg) seem to have received sediment supply from the east. Due to the high economic importance of these sediments, the stratigraphy and palaeoenvironment of this part of the North Sea Basin are well known (see Stewart, 1987 and, for a review, Lovell in Glennie, 1990).

Although concentrating on areas somewhat to the north of the wells examined in this study, it is worth summarising the work of these previous authors:

Parker (1975) recognised large-scale top- fore- and bottom-set units from the Palaeocene. Coal and shell bands recorded in the top-set units in the Moray Firth area suggest that deposition occurred under a shallow marine, coastal plain type environment. Fore-set and bottom-set clays and turbiditic sands were laid down in a deeper (several hundreds of metres; Parker, 1975; Ziegler, 1981) marine setting in the forms of tongues and lobes.

Text Figure 3 Regional Setting of the Study Area during the Palaeocene (after Ziegler, 1990)

Fig. 64. Paleocene framework of North Atlantic domain. Abbreviations: ALB-Alboran-Kabylia Block, CGFZ-Charlie Gibbs Fracture Zone, FC-Flemish Cap, GB-Grand Banks, IM-Irish Massif, LUC-CAMP-Lucania-Campania Block.

Later, Morton (1979, 1982); Rochow (1981) and Knox *et al.* (1981) refined this single-phase depositional model into one of several distinct depositional pulses which were developed in response to changes in subsidence and uplift patterns. The main depocentre alternated between the Central Graben and the Moray Firth Basin and events were summarised as follows:

1) The introduction of sands from the East Shetland Platform caused by subsidence in the Central and southern Viking Grabens.

2) The introduction of sands from the Scottish highlands caused by subsidence of the Moray Firth Basin.

3) The renewed introduction of sands from the East Shetland Platform (as the Forties Formation/Member) into the subsiding Central Graben.

4) Further subsidence of the Moray Firth Basin associated with the development of the coastal plain complex.

Stewart (1987) recognised a total of 10 depositional systems in the Palaeocene and earliest Eocene of the Central North Sea, with sea level "highstands" in the late Danian, and early and late Thanetian. He also indicates at least five hiatuses over this interval. A more detailed discussion of Stewart's work is given in Chapter 6.

However, lack of economic interest and published data from the Palaeocene of the south Central and Southern North Sea areas prevents full application of these models in those regions. The absence of an appropriate local sediment source area (i.e. the Shetland Platform) and bathymetric estimates for the area (i.e. shallow waters), together with regional palaeogeographical considerations, suggests that sediment accumulation and distribution were largely controlled eustatically by a relatively mobile shoreline. Land relief to the west (i.e. southeast and eastern England) was relatively low and flat and probably contributed little sediment to the southern reaches of the Basin (Murray, 1992).

Previously published literature on foraminiferal distributions in the Late Palaeocene (Thanetian) of the North Sea region can also provide valuable palaeoenvironmental information. For the planktonic foraminifera, the cautionary points made above regarding their palaeoenvironmental use in the Danian apply less in the Late Palaeocene. Many of the early workers on Lower Palaeogene planktonic foraminiferal biostratigraphy from tropical areas (e.g. Bolli, 1957 and Loeblich & Tappan, 1957 - see chapter 7.2.1) demonstrated that relatively "advanced" taxa, for instance keeled forms such as *Planorotalites pseudomenardii* (Bolli) and *Morozovella conicotruncata* (Subbotina) had evolved by the early part of the Late Palaeocene and became very diverse by the end of the Palaeocene. However, most published accounts of the North Sea Basin (Crittenden, 1979, 1981, 1982 & 1986; King, 1983 & 1989; Copestake & Dyer, 1981) and surrounding areas (Haynes, 1954-8; Wood & Haynes, 1957; Haynes & El-Naggar, 1964; Barr & Berggren, 1964; Berggren, 1965; El-Naggar, 1967; Murray *et al.*, 1981 & 1989 [U.K.]; Brotzen, 1948; Reichel, 1953; Bang, 1969 & 1979; Troelsen, 1957; Berggren, 1960 & 1962; Brönnimann, 1952; Hansen, 1970b; Hansen & Andersen, 1969; Hofker, 1960b; Larsen & Jorgensen, 1977 [Scandinavia]) contain no references to these types of taxa. Their absence in the North Sea region is due to unsuitable conditions of temperature and/or salinity and/or bathymetry.

The acquiring of a keel has been suggested to be an adaptation to cool waters (Bandy, 1964) as well as an adaptation to a deep dwelling existence for at least some of the life-cycle (see below). As far as keels are a sign of adaptation to cool waters, Bandy (1964) states that keeled globorotaliids are characteristic of surface water temperatures of 17°C or greater, whilst unkeeled forms can exist in waters of surface temperature as low as c.9°C. It is possible to delineate a "keeled planktonic foraminiferal latitude datum" which may be traced back through time (Bandy, 1964; Szczechura & Pozaryska, 1976). These workers show that during the Palaeocene, the northerly limit of the datum in the North Sea area was at approximately 49°N, i.e. through NE France, S.Netherlands and eastwards through Germany. To the south of this datum keeled (and angulate) forms predominate whilst to the north, "globigerine" forms are dominant. However, this does not necessarily completely exclude one type from another's realm. Also, short-term influxes of warm water into the southern reaches of the North Sea area may allow the periodic introduction of keeled globorotaliids.

The presence of a keel as an adaptation to being able to spend at least part of the life-cycle in deep waters has been discussed by Hart & Bailey (1979) and Hart (1980) for Cretaceous planktonic foraminifera. The hypothesis is that (presumably non- or slightly- keeled) juveniles in the surface waters acquire keels and migrate downwards through the water column to spend their adult existence at great depth. Some recent keeled and thick-walled species have been recorded as being alive when caught from depths exceeding 2000 metres in the Pacific Ocean (see Bé & Tolderlund, 1971). They are presumed to later return to the surface waters after reproduction.

The presence or absence of keels should not be assumed to convey any sort of hydrodynamic advantages to the owner. Studies on living planktonic foraminifera (e.g. Bé, 1977) show that the test is nearly completely enveloped by the animal's cytoplasm and it is the surface of this soft matter, and perhaps some spines, that are in contact with the surrounding water. Rather, it is thought, that the keels may form loci for deposition of

additional calcitic material that provides extra weight to the organism which allows it to sink in the water column. The animal may be able to return to the surface waters by increasing the production of fatty matter in its cytoplasm which is, in any case, much less dense than sea water.

Recent specimens trawled from surface waters (i.e. the top 50m) are almost exclusively dominated by non-keeled and thin-walled types (Bé & Tolderlund, 1971). The absence of keeled or thick-walled species from fossil assemblages that contain non-keeled and/or thin-walled surface dwellers would imply that palaeodepths were insufficiently great to allow the existence of such taxa when alive. A few specimens may be expected to drift into shallower waters occasionally but these occurrences should be rare.

The predominance of thin-walled and/or non-keeled taxa in the Late Palaeocene North Sea assemblages noted above would seem to indicate that palaeodepths throughout much of the southern and surrounding parts of the North Sea were rather shallow.

However, Corfield (1986) quotes oxygen isotope data from studies on (amongst others) Palaeocene planktonic foraminifera which seem to indicate the reverse, i.e. keeled forms predominantly come from shallower waters and globigerine forms from deeper waters. This would appear to contradict the biological evidence and the empirical evidence presented above for Recent planktonic foraminifera. Corfield's interpretation of the data is still, apparently, under question (Hart *pers. comm.*).

A relatively shallow palaeodepth model for most of the southern North Sea is in some way supported by the benthonic foraminifera from the same areas. Haynes (various related papers; 1956-1958) has proposed a palaeoenvironmental interpretation of the Thanet Formation of Kent based on the foraminifera. He has identified a series of four "ecological faunules" which are related to fluctuating transgressive and regressive episodes within an overall deltaic environment. This has subsequently been further refined by Haynes (1981) and these faunules are described below. Murray *et al.* (1981) have reviewed the foraminifera from the Palaeogene sediments of southern U.K. and also discusses their palaeoenvironmental utility.

Haynes has suggested that the Bullhead Conglomerate Member represents the initial inundation surface which was very rapid. No foraminifera were recovered from this unit. The succeeding Stourmouth Clays also yielded no foraminifera and are thought to have been deposited under quiet, estuarine conditions which are unfavourable to foraminifera.

The first of Haynes' faunules **"Faunule 1" (*Bulimina thanetensis* zonule)** occurs in the basal part of the lower Pegwell Marls with *Alabamina obtusa* (Burrows & Holland), *Cibicides proprius* (Brotzen) (= *Cibicidoides alleni* (Plummer) herein), *Cibicidoides succedens* (Brotzen) and *Hollandina* (= *Heterolepa* herein) *pegwellensis* Haynes dominant. There is also a high proportion of agglutinated taxa. A transitional marine to midshelf (10m-60m water depth) environment is envisaged for this zonule and, according to Haynes, is comparable to a similar Palaeocene littoral marine microfauna found in Holland by Ten Dam (1944).

"Faunule 2" (*Glomospirella woodi* zonule) above yielded a sparse agglutinated fauna which represents dysaerobic bottom waters and indicates a change to more restricted marine conditions.

"Faunule 3" (*Cibicides proprius* zonule) occurs in the Upper Pegwell Marls Member and contains an abundant microfauna dominated by *Cibicides* spp., *Bulimina* spp., *Gyroidina* spp. and *Hollandina* spp. More open marine conditions are indicated to have returned and middle shelf palaeodepths (20m - 100m) are envisaged. This zonule represents the maximum phase of marine transgression. A gypsiferous band within this unit contains an impoverished agglutinated microfauna ("Faunule 3a") which suggests reducing conditions at or below the sediment - water interface. "Faunule 3b", which lies above, contains more calcareous taxa and represents a period of shallowing and increased bottom water oxygenation caused by the approach of the delta front.

"Faunule 4" (*Cibicides cunobelini* zonule) occurs within the cross bedded Reculver Silts (at Pegwell and Reculver) and is dominated by *Cibicides* spp. and *Textularia thanetana* (Lalicker) (= *Spiroplectammina thanetana* (Lalicker) herein) The cross bedding suggests shoal conditions. Later Haynes (1981) modified this somewhat and suggested shallow shelf conditions with strong deltaic influences although well away from the delta front. The Reculver Silts developed at Reculver were assigned to "Faunule 4b", deposited under hyposaline / deltaic conditions.

The Woolwich Beds overlying the Reculver Silts at Reculver were interpreted by Haynes as a phase of oscillatory regression, essentially barren of microfossils.

Haynes (1981) therefore suggested that the Pegwell Marls and the Reculver Silts represented respectively the transgressive and regressive phases of a "Stamp - type" (Stamp, 1921) cycle. Haynes (1958c) remarked on the close similarity between five-fold phases of deposition recorded from the American Gulf Coast Tertiary and those of the Thanet Cycle. (The absence or scarcity of planktonic foraminifera indicated that open oceanic marine influences were negligible):

Cycle Phase	**Deposition**	**Thanet Cycle Representative**
(e)	Continental sands	Reading Beds
	---------- sharp change ----------	
(d)	Less fossiliferous shales and sands which which display oscillatory regression effects	Woolwich Beds
	---------- sharp change ----------	
(c)	Regressive conditions in the upper parts of the shale members	Reculver Silts (?+ topmost Pegwell Marls)
	---------- gradual but oscillatory change ----------	
(b)	Rapid transgression and slow deposition thereafter	upper Pegwell Marls
	---------- sharp change ----------	
(a)	Initial transgression with deposition of a transitional member	lower Pegwell Marls & Stourmouth Clays (presumeably including the Bullhead Member).

On a rather more global scale, Palaeocene benthonic microfaunas have been recognised from every continent. They have been differentiated into three basic "types", each being primarily depth controlled. The character and distribution of the benthonic assemblages recorded in this study can be related to these "types" and additional palaeoenvironmental information can be obtained.

Berggren & Aubert (1975) discussed the distribution of Palaeocene benthonic foraminifera from the Atlantic-Tethyan region and recognised three distinct assemblage types termed "Tethys Carbonate Fauna" (TCF), "Midway" and "Velasco" (the later two after the two formations in North America where the assemblages are well developed and where they were first recognised). The assemblage types are almost worldwide in their distribution and characteristic species are extremely cosmopolitan within their respective assemblage types.

The cosmopolitan nature is thought to be due to more equable climatic conditions prevailing during the Palaeocene resulting in a lower polar to equatorial thermal gradient, together with warmer oceans with a more uniform thermal structure to them. The primary cause of this equable climate was mainly palaeogeographical distribution of the continents and the associated palaeo-oceanographic effects.

Berggren & Aubert (1975) have described the setting of the major continents during the Palaeocene (after Berggren & Hollister, 1974). In summary, the Atlantic ocean was bordered towards the north by N.America (to the NW), Greenland (to the North) and Europe (to the NE). A wide connection to Tethys was in place towards the east between the European and African plates and a relatively narrow seaway existed between N.America and Greenland (the present day Labrador Sea). Circulation patterns in this ocean were predominantly clockwise with a proto-Gulf Stream introducing relatively warm waters into NW Europe. During the "Middle" Palaeocene (c.60 m.y.b.p.) active spreading in the North Atlantic switched from the more northwesterly Labrador Sea to a more northeasterly direction which opened a seaway between Europe (including Norway) and Greenland. This introduced cold "Boreal" Arctic waters into northwest Europe and effectively isolated the North Sea from warmer Atlantic influences. The effect on Palaeocene assemblages, both planktonic and benthonic were profound and discussed below.

Of Berggren & Aubert's (1975) three Palaeocene benthonic assemblages, the first, the **"Tethys Carbonate Fauna"**, is characterised by various cibicidiids, nonioniids, rotaliids, discorbids, elphidiids and assorted "larger" foraminifera (e.g. *Nummulites*, *Alveolina* etc.), which, as it's name indicates, developed in carbonate environments of the Tethys Sea. It is primarily a shallow water (<30m - 50m) inner to middle shelf assemblage. Assemblages of this type are not encountered in northwest Europe until the Eocene where the occurrence of *Nummulites* spp. and others has been well documented. One major difference in these European forms is that although the microfaunal association is present, it is not developed in the appropriate lithofacies i.e. carbonate. Berggren & Aubert (1975) themselves imply that this association is confined to circum-Tethyan regions.

The second and third assemblage types are more applicable to the kind of benthonic microfaunas seen in Northwest Europe and are discussed in detail below. It should be stressed that the boundary between the two assemblage types is not clearly obvious and some degree of intermingling of characteristic taxa can be expected, particularly along the upper continental slope.

"Midway type" microfaunas:

Midway type microfaunas are characterised by abundant and diverse smaller calcareous benthonic foraminifera, mainly lagenids, cibicidiids, anomalinids, lenticulinids, nodosariids and vaginulinids. Agglutinated taxa (ammobaculitids, spiroplectamminids and textulariids) are also common but subordinate to the calcareous benthos. These assemblages are almost always associated with primarily clastic deposition and have been recorded worldwide.

Berggren & Aubert (1975) in a highly comprehensive study which cannot be adequately reproduced here, compare and contrast the Midway type microfaunas recorded by various authors from many worldwide localities including-

North America:	Midway, Wilcox, Rancocas, Vincetown, Aquia and Sabine.
South America:	Soldado and Lizard Springs.
North Atlantic:	West Greenland, Rockall Bank and Norwegian Sea.
Europe:	Scandinavia (mainly Sweden & Denmark), Holland, Belgium, England, France, Germany and Poland.
Africa/Mid East:	Egypt, Algeria, Libya, Saudi Arabia, Morocco, Tunisia, Lebanon and Syria.
Soviet Union:	Various locations particularly around the Crimea, Ukraine and Tadzhikistan together with western Siberia.
Oceania:	S.Australia, SW New Zealand and the Tasman Sea.

After exhaustively comparing and contrasting various worldwide assemblages and taxonomies, they conclude that the Midway type microfauna is characterised by the following species: *Cibicidoides alleni* (Plummer), *C.howelli* (Toulmin), *C.succedens* (Brotzen), *Anomalinoides acuta* (Plummer), *Alabamina midwayensis* (Plummer) (= *A.obtusa* (Burrows & Holland) herein), *Gavelinella danica* (Brotzen), *G.neelyi* (Jennings) and *Osangularia plummerae* Brotzen, as well as various lagenids (nodosariids, lenticulinids and vaginulinids), polymorphinids and textulariids.

The "Midway type" microfauna is characterised as a middle - outer shelf assemblage of approximately 50m-200m water depth.

It is apparent that assemblages recorded from onshore northwest European localities are closely related to the Midway type assemblages of Berggren & Aubert (1975). It will also become apparent that assemblages described in this study from the (especially Southern) North Sea also belong to this assemblage type. King (1989) approximates his "outer sublittoral" biofacies (biofacies 2a) from the North Sea with a "Midway type" assemblage (see Chapter 7.2.2).

"Velasco type" microfaunas:

Velasco type microfaunas are characterised by robust anomalinids (*Gavelinella beccariiformis* (White), *G.rubiginosa* (Cushman) (=*G.danica* (Brotzen) herein), *G.velascoensis* (Cushman), *Nuttalides truempyi* (Nutall), *N.florealis* (White), *Osangularia velascoensis* (Cushman) and *Aragonia velascoensis* (Cushman)) lagenids including nodosariids (*Nodosaria velascoensis*) and dentalinids (*Dentalina limbata*) small agglutinated forms (*Gaudryina pyramidata, Tritaxia apera* and *Dorothia* ex gr. *oxycona trinitatensis*) and various gyroidinids and buliminids. They are considered to be characteristic of continental slope, continental rise and abyssal plain environments with water depths of 200m or more.

Tjalsma & Lohmann (1983)[1] recognised several different deeper water biofacies in their study material from the Atlantic Palaeogene. Although they do not use the term "Velasco" throughout their publication the present author has assumed that their biofacies can be grouped together under this term.

The deepest biofacies encountered is dominated by *Nuttallides* spp. and ranges from the Early Palaeocene to the late Middle Eocene. A second, shallower biofacies is dominated by *Gavelinella beccariiformis*. The *Nuttallides* biofacies gradually expanded its bathymetric range from abyssal depths to middle bathyal depths throughout the Palaeocene, replacing the shallower *Gavelinella* biofacies and driving it upslope into shallower waters where it subsequently disappeared close to the Palaeocene - Eocene boundary.

An increase in evolutionary appearances of new taxa then occurred and the *Nuttallides* biofacies returned to abyssal depths where it became extinct in the late Middle Eocene. At approximately the same time, two taxonomically and bathymetrically distinct biofacies developed in the Early and Middle Eocene. The deeper biofacies is characterised by *Globocassidulina subglobosa, Gyroidinoides* spp. and *Cibicidoides ungerianus* (d'Orbigny), whereas the shallower biofacies is dominated by *Lenticulina* spp. Both biofacies maintained their depth distribution until the end of the Eocene.
Certain North Sea microfaunal assemblages, particularly towards the Central and Northern North Sea areas, may correspond to the Velasco type association described above. King

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[1] Berggren & Aubert (1975) summarise but do not discuss the characteristics of the Velasco type microfaunas in detail. They state that a colleague (R.C.Tjalsma) would publish on the Velasco type faunas but the present author could not trace such a publication. However, R.C.Tjalsma and G.P.Lohmann published work on Atlantic Palaeogene abyssal foramininfera (1983) which forms the basis for the above discussion.

(1989) approximates the Velasco type microfaunas to his "epibathyal biofacies" (biofacies 2b) - see Chapter 7.2.2.

Van Morkhoven *et al.* (1986) examined the distribution of deep water benthonic foraminifera throughout the Cenozoic. They recognised several groups of selected taxa with different upper depth limits in (for example) the Palaeocene and Eocene:

Upper Depth Limit	**Palaeocene**	**Eocene**
Middle Neritic (30-100m)	*Bulimina midwayensis* *Anomalinoides danicus* *Anomalinoides lellingensis* *Cibicidoides alleni* *Osangularia plummerae* *Stensioeina parvula* *Tritaxia midwayensis*	*Bulimina jacksonensis* *Anomalina bilateralis* *Uvigerina gardnerae* *Planulina cocoaensis*
Upper Bathyal (200-300m)	*Neoflabellina delicatissima* *Coleites reticulosus* *Cibicidoides dayi* *Angulogavelinella avnimelechi* *Dorothia oxycona* *Gaudryina pyrimidata*	*Cibicidoides eocaenus* *Vaginulinopsis decorata* *Anomalinoides capitatus* *Uvigerina rippensis* *Turrilina robertsi* *Spiroplectammina spectabilis* *Valvulina mexicana* *Gaudryina hiltermanni* *Planulina costata*
M.-U. Bathyal (500-700m)	*Bulimina trinitatensis* *Bulimina velascoensis* *Nuttallides truempyi* *Stensioeina beccariiformis* *Osangularia velascoensis* *Spiroplectammina spectabilis*	*Bulimina jarvisi* *Bulimina trinitatensis* *Bulimina tuxpamensis* *Cibicidoides tuxpamensis* *Nuttallides truempyi* *Osangularia mexicana* *Hanzawaia ammophilia* *Cyclammina* spp.

In summary, the southern parts of the North Sea region (including the Southern North Sea, southern U.K., Scandinavia and the European countries bordering the area to the south) during the Late Palaeocene (Thanetian) lay under a broad, fairly shallow and relatively cool semi-enclosed sea. The western margin was largely deltaic and the palaeoshoreline around the area seems to have shifted frequently and, because of the shallow waters, with relatively large lateral magnitude.

However, a rather different interpretation can be made further northwards into the central and northern parts of the North Sea when viewed in the light of other foraminiferal evidence. Publications on the Early Palaeogene foraminiferal microfaunas of the Central North Sea area are rare (Gradstein & Berggren, 1981; Charnock, 1983 - unpublished M.S.; King, 1983 & 1989) but significant in that the microfaunas they describe are radically different from those of contemporaneous microfaunas to the south.

The microfaunas in question are comprised, almost exclusively, of agglutinating foraminifera, the majority of which use non-calcareous material in their test wall construction. Some agglutinated foraminifera do use calcareous cement in test wall construction, however it is the former type that are referred to throughout the rest of this work. Assemblages of this type had previously been recorded by several authors (including Grzybowski, 1894-1901; Geroch, 1959, 1960; Geroch *et al.*, 1967; Brouwer, 1965; Jednorowska, 1968; - see Gradstein & Berggren, 1981 for a review) from flysch deposits around the world. Flysch deposits are thick fine-grained clastics that accumulated in foredeeps during the active uplift phase of a geosynclinal belt (Gradstein & Berggren, 1981). They have been found worldwide but the term is more usually associated with the flysch sediments deposited on the north side of the Alpine geosyncline during Late Cretaceous to Palaeogene times. It is not surprising then that this characteristic agglutinated assemblage has been termed "flysch type foraminifera". Flysch type assemblages (from Gradstein & Berggren, 1981) on the whole...

- occur in the pelitic interval of turbidite sequences
- are dominantly siliceous agglutinated with, at best, rare calcareous elements
- are moderately diverse but not particularly abundant
- have a cosmopolitan distribution
- contain predominantly single-chambered and uniserial genera.

Of particular relevance to this section of the study are the palaeoecological implications of such a microfauna (for their biostratigraphic utility see Chapter 7.2.2). One major problem in respect of the palaeoenvironmental interpretation of these faunas is that they have no direct modern analogues. However, Gradstein & Berggren (1981) provide an excellent review of the many and varied proposed palaeoecological significances of flysch-type agglutinated microfaunas and themselves describe extensive flysch-type assemblages from the Maastrichtian - Palaeogene of the North and Labrador Seas. More recently, Miller *et al.* (1982) examined similar assemblages from similar aged sediments from boreholes in the Labrador Sea. Charnock (1983, unpublished MS) described a diverse agglutinating assemblage from an unnamed well in the Central North Sea and King (1983 & 1989) also describes agglutinated taxa from the North Sea offshore in general.

Between these workers and others working on similar assemblages outside the North Sea region, many different environmental factors controlling the distribution of such assemblages have been suggested. They can be grouped into bathymetry, sediment surface characteristics and, together, water chemistry, physics and hydrographic properties. However it seems likely that there is no single primary control and a combination of two or more principal factors may be needed to account for these assemblages.

1) **Bathymetry**

Brouwer (1965) coined the term "*Rhabdammina* fauna" after the dominant genus recorded in his study of the Alpine flysch. He postulated a very deep water origin for these assemblages. He compared his findings with those of Brady, 1884 and Saidova, 1961, who described similar assemblages from the Recent deep-sea abyssal plain (below 3000m) below the Calcium Carbonate Compensation Depth (CCCD) i.e. the level in the oceans below which solid $CaCO_3$ goes into solution. Thus the absence of calcareous organisms is caused by the instability of calcite below the CCCD with very low (1-1.5°C) temperatures and high pressures. Moorkens (1976) however, indicates that such agglutinated assemblages can occur in upper bathyal or even outer neritic depths in northwest European Early Tertiary basins. Miller *et al.* (1982) from their studies in the Labrador Sea noted a constant value of calcium carbonate in sediments across a boundary which saw a major faunal change. Eocene assemblages of predominantly agglutinating taxa are replaced, rather abruptly, by an Oligocene assemblage of calcareous benthonic taxa. This would seem to suggest that calcium carbonate was available at the time of the existence of the agglutinating assemblage and thus these assemblages are not exclusive to depths below the CCCD. Berggren & Aubert (cited as in press in Gradstein & Berggren, 1981) describe a diverse agglutinated assemblage from the Palaeocene - Eocene of California which may have been deposited in as shallow palaeodepths as 200m (outer neritic). The same fauna is noted by them 300km away in arkosic sands from the distal end of a turbidite fan (1-2km palaeodepth). Finally, it is well known from studies on present day agglutinated foraminifera that they can exist to the exclusion of most other types in the very shallow waters of marginal marine marshes and brackish estuaries (see Haynes, 1981).

This shows that depth *per se* does not control the presence of agglutinated assemblages of the *Rhabdammina* fauna type.

2) **Sediment Surface Characteristics**

The abundance of agglutinated foraminifera in turbidite type deposits was, according to Ksiazkiewicz (1961) due to the high availability of suitable test-building material brought in by turbidity currents which conveniently sorted the size-factions of sediment grains with the finest grains accumulating on the surface of the turbidite deposit. Miller *et al.* (1982) however, stated that lithology was constant across their major faunal boundary at the

Eocene/Oligocene in the Labrador Sea. The local extinction of the agglutinated microfauna was not therefore, they suggest, caused by a change in substrate characteristics.

3) **Water Chemistry, Physics and Hydrographic Properties**

Saidova (1960, 1965 and 1976) suggested that the distribution of agglutinated assemblages in the Recent abyssal environment of the Pacific was linked to latitudinal factors of temperature and salinity and hyposometric factors such as temperature (vertical), pressure and dissolved oxygen. The high pressures, low temperatures and low O_2 levels found in this environment are conducive to the development of this type of assemblage. These conditions, which also include slightly reduced salinity, would also inhibit $CaCO_3$ accumulation and impede its use as a test construction material.

Greiner (1969) suggests the fundamental factor governing the occurrence of benthonic foraminifera is the availability of $CaCO_3$. The organic cement of many agglutinated foraminifera (Hiltermann, 1973) is insoluable in CO_2-rich bottom waters which would otherwise hamper the production of calcareous tests or corrode those that are introduced into the area. This is suggested to explain why agglutinated foraminifera are abundant in environments low in $CaCO_3$, low in salinity and low in temperature and/or O_2 and have fluctuating pH values. Such environments include marginal marine and brackish waters as well as the deep ocean basins (see also Murray, 1973, 1992). It also explains why agglutinated foraminifera are more common in higher latitudes as $CaCO_3$ is more soluble in colder waters.

High latitudes also tend to produce $CaCO_3$-poor terrigenous runoff which, together with factors described above, can raise the level of the CCCD (400m in the Ross Sea of Antarctica - Fillon, 1974). The CCCD can also be shallow along continental margins (see Hesse & Butt, 1976). High sedimentation rates may decrease the biogenic carbonate concentration due to dilution effects. The abundance of organic matter would produce higher CO_2 levels and would also lower pH levels at or below the sediment - water interface (see subsection iii below). Conditions somewhat similar to this exist around large deltas where carbonate poor/free sediments on the delta slope may be replaced seaward by carbonate-rich sediments (Hesse & Butt, 1976).

Moorkens (1976) has suggested that three (and later, 1983, added a fourth) main chemical / physical factors are important in favouring the development of flysch-type agglutinating foraminiferal assemblages:

i) the rapid deposition of fine-grained organic-rich sediments in stagnant, poorly circulating bottom water conditions usually found in silled basins and topographically low areas.

ii) low (<7.8) pH values which are caused by a high CO_2 content. This high CO_2 content can be caused by:

- *in situ* decaying organic matter or
- occurring in cold, deep waters where it is induced by low temperatures and high pressures.

The high CO_2 (and low O_2) inhibits production and fossilisation of a calcium carbonate test and impedes aerobic bacterial activity.

iii) negative or low positive Eh values (However, this is more of a function of ii) above as these Eh values are produced by low pH and low O_2 levels) under reducing conditions. The reducing conditions in question may occur below the sediment - water interface, even as shallow as 1mm below, in an otherwise normally oxygenated environment. Consequently, a calcareous microfauna that may be thriving on the sediment surface would be removed by dissolution on burial after death.

iv) availability of iron may also be important, mainly for the more primitive Astrorhizidae, which require the element in order to secrete ferric oxides as a test cement.

The physico-chemical conditions outlined above can explain the formation of a flysch-type agglutinated foraminifera assemblage without the need to introduce water depth (bathymetry) as a primary causal factor. Some of the conditions described above can be found in deep water environments but depth is not their cause *per se*.

It is interesting to note that the physico-chemical conditions conducive to development of flysch-type assemblages form much of the requirements for the deposition of hydrocarbon source rocks. Although any real evidence for a link, particularly in the North Sea, has yet to be adequately demonstrated. However, the organic-rich succession of the Kimmeridge Clay[2] of Dorset contain (virtually) only agglutinated foraminifera with calcareous taxa present mainly above and below.

Insofar as these assemblages can help elucidate the palaeogeography / environment of the central area of the North Sea, they can provide much useful information. Charnock (1983 - unpublished MS) has collated much data on the ecological preferences of modern day agglutinated genera and species. This information shows that most genera exist over quite

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[2] The principal source-rock for oil in the North Sea

substantial bathymetric ranges e.g. *Rhizammina* (150m-4820m); *Ammodiscus* (36m-5929m) and *Ammobaculites* (11m-7228m) are typical. Similarly at the species level, this trend is repeated with some species showing wide bathymetric ranges though they may be restricted in discrete areas e.g. *Glomospira gordialis* (Jones & Parker) (an extant species also recovered from the North Sea Palaeocene) occurs shallower than 200m west of California (Bandy & Chierci, 1966) but at depths greater than 2500m on the Newfoundland Slope (Schafer *et al.*, 1981) (see Charnock, 1983 - unpublished MS for more examples). However, there seems to be a preference (though not exclusively) for existence at depths below 200m.

Comparison with modern analogues can also assist. Charnock chooses five widely spaced geographical localities {the Peru-Chile Trench (Bandy & Rodolfo, 1964); the Gulf of Mexico (Le Roy & Hodgkinson, 1975); the Skagerrak (Hoglund, 1947); the Newfoundland Slope (Schafer *et al.*, 1981) and the Antarctic Slope (Milam & Anderson, 1981)} and compares their agglutinated assemblages with those published from the North Sea.

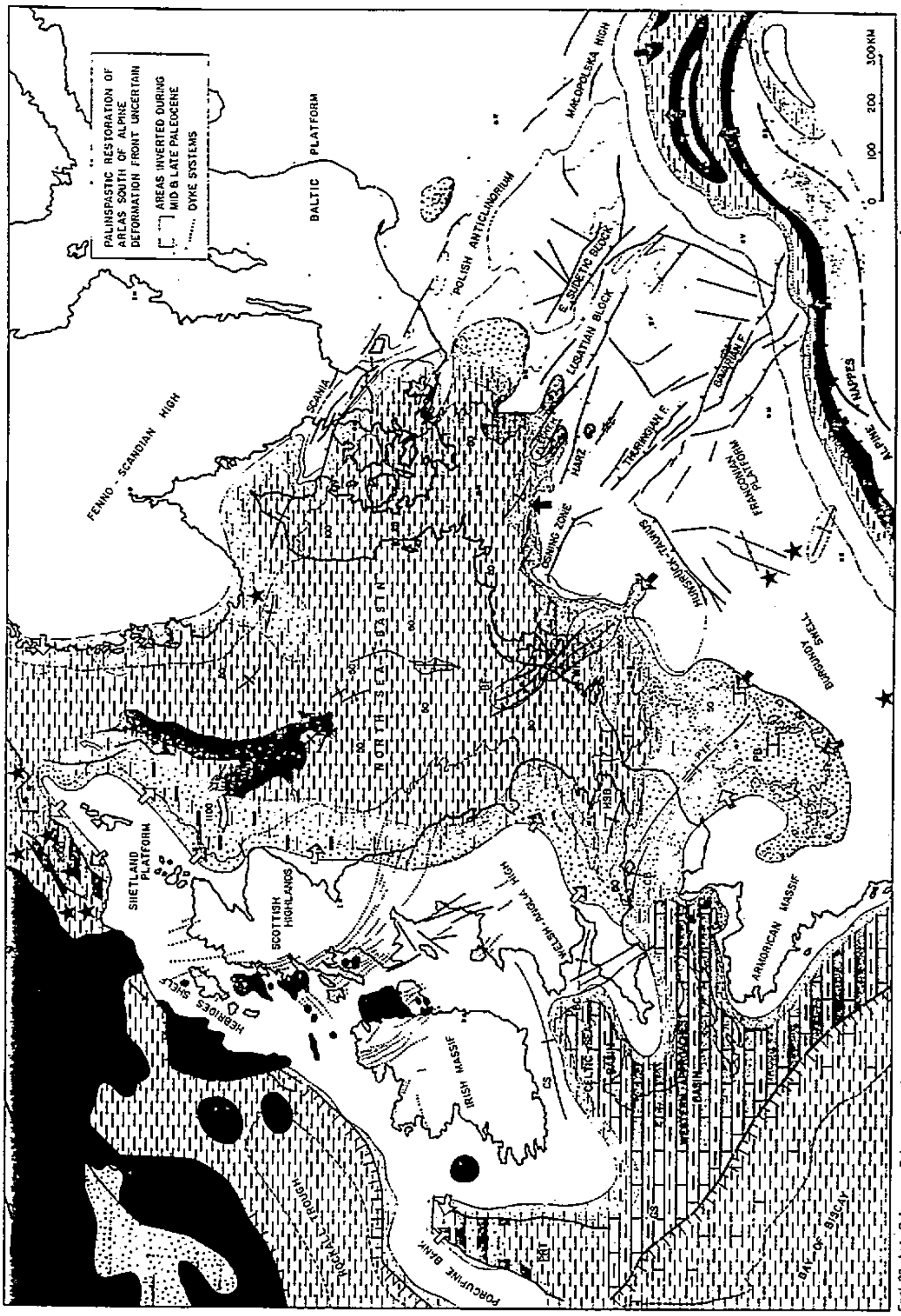
According to King, 1989, agglutinants typical of the "*Rhabdammina* biofacies" first appear in the North Sea Tertiary in the basal Late Palaeocene. He considers this to be coincident with the base of a low sea-level phase (cycle TP 2.1 of Vail *et al.*, 1977, see also Haq *et al.*, 1988 and Text Figure 14) during which conditions for the development of the biofacies were at their best.

The picture emerges (see Text Figure 4 and Text Figure 5) of the central area of the North Sea (Outer Moray Firth / Central Graben) during Late Palaeocene times as probably close to the locus of maximum sediment deposition and maximum palaeodepths during this time. The sea would have been enclosed on nearly all sides with an opening probably in the north connecting to an open Boreal ocean via the Norwegian - Greenland rift. Clearly, adequate vertical water circulation in such a sea would have been difficult to establish, let alone maintain, and comparative stagnation (below surface waters that could have been mixed by wave action) would have soon developed. This surface mixing, renewing O_2 levels in surface waters, may have been sufficient to support a thriving surface plankton such as planktonic foraminifera, nannoplankton, dinoflagellates, planktonic diatoms and radiolaria, which would have contributed to high organic productivity.

Sediment input into the area (from the emergent Shetland Platform and the Scottish Highlands plus possible sources to the east) was rapid and probably fairly continuous. These factors would have been conducive to forming the physico-chemical conditions (high CO_2 levels, low O_2 levels and low pH values) necessary for the establishment of a thriving agglutinated assemblage. Calcareous organisms may have also existed side by side with the agglutinants, at least, those forms more tolerant of low $CaCO_3$ conditions.

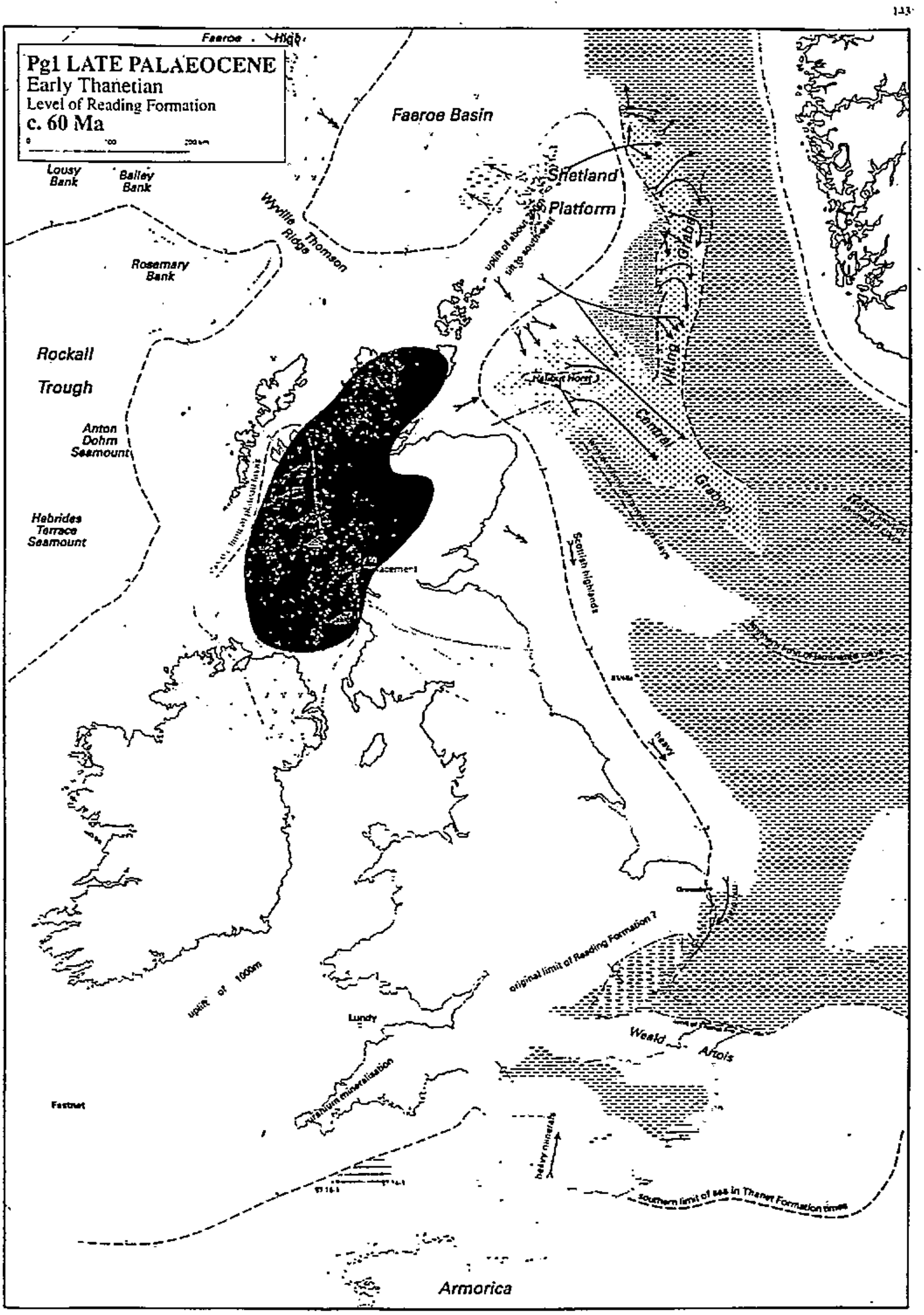
Reducing conditions just below the sediment - water interface would, however, have removed any trace of a calcareous organism soon after burial after death. Non- calcareous planktonic organisms such as dinoflagellates and diatoms recovered, sometimes in abundance, from Late Palaeocene North Sea sediments, support the suggestion of a productive phytoplankton.

Text Figure 4 **Generalised Late Palaeocene Palaeogeography (after Zeigler, 1990)**



Encl. 33. Late Palaeocene Palaeogeography (main sources: Anon, 1964, [illegible] et al. 1986, [illegible], 1986, [illegible], 1971, [illegible] and Dillon, 1974, [illegible], 1960, [illegible], 1980, [illegible] 1978 Vinken, 1988)

Text Figure 5 **Generalised Late Palaeocene Palaeogeography (after Murray, 1992)**



2.3.3. Latest Palaeocene - Earliest Eocene Palaeogeography

Knox *et al.* (1981) suggests that the switching of depocentres and source areas mentioned previously in this section are probably tectonically controlled, being related to impending plate-separation between Greenland and Rockall in the Early Eocene. The accompanying volcanic activity left a widespread mark in northwestern Europe with the deposition of laterally extensive tuffs with volcanic glass shards throughout most of the area. An alternative (or indeed additional) volcanic source area for these tuffs has been postulated from a volcanic province in the Skaggerak area (Bonde, 1974 and Soper *et al.*, 1976).

This so-called "ash marker" is several tens of metres thick across the region and is found throughout most of the North Sea (as the Balder Formation) and also outcrops in Denmark, Germany, the United Kingdom and The Netherlands. Several phases of ash deposition have been recorded from the North Sea area, particularly in the north around the Halibut Horst, Forties area and Viking Graben. The earliest phase is dated as lowermost Thanetian.

Nearly 200 individual ash layers have been delineated in the Mo-clay of Denmark (Jacqué & Thouvenin, 1975). A characteristic and mainly pyritised planktonic diatomaceous microfauna has been recorded from these ash (i.e. latest Palaeocene - early Eocene) layers by several authors in and around the North Sea area {Staesche, 1938 and Bender, 1972 (from Germany); Jacqué & Thouvenin, 1975 and Crittenden, 1979 (from the North Sea); Haynes in a pers. comm. to Crittenden, 1979 (from the Thanet Formation of the U.K.); Davis & Elliot, 1958 (from the lower London Clay) and Berggren, 1960 (from the lower Ypresian of The Netherlands)}. The palaeogeographical/environmental implications of this microfauna are not inconsequential. Jacqué & Thouvenin (1975) argue that the presence of abundant pyritised diatoms is, in itself, indicative of tuff formation. They do, however, go on to state that the distribution of these diatoms (specifically *Coscinodiscus* sp.*1*) is not limited to the tuff zones but may be found as high as the Miocene. They suggest that diatoms were common in the surface waters during periods of volcanic ash input due to silica enrichment of the sea water which is, in turn, conducive to diatom "blooms".

Alternatively, Bonde (1974) considers the gross physical shape of the Late Palaeocene - Early Eocene North Sea which was almost fully enclosed with a northernwards opening via the Norwegian Sea. Prevailing winds were from the northwest (which also were responsible for the wind-blown transport of ash from the Hebbridean Volcanic Province) and created a surface current in this almost enclosed sea. The resultant upwelling would have brought abundant nutrients into the surface waters which would have supported a large planktonic biomass. The consequent subsurface counter-current would remove subsurface nutrients and cause a dysaerobic environment at depth (i.e. on the sea floor). The overconsumption

of oxygen at the surface (by the plankton) may further reduce O_2 levels at the sea floor and the increase in organic input would compound this.

The dysaerobic bottom waters would have provided chemically reducing conditions which would prevent the existence or preservation of organisms with calcareous shells (i.e. calcareous benthonic and planktonic foraminifera, ostracods etc.) but would, however, be more conducive to the preservation of siliceous organisms, particularly if pyritised, or other non-calcareous organisms such as agglutinated foraminifera.

However, benthonic assemblages from this time-interval in the North Sea Basin are subtly different from those occurring above and below. Although agglutinating taxa are present, they are not of the "*Rhabdammina* biofacies" type (see King, 1989 fig. 9.14) and co-exist with, albeit rare, calcareous benthonic foraminifera (Zone NSA 2 of King, 1989). King therefore suggests that palaeodepths during this time were comparatively shallow and appear to equate with the Late Palaeocene sea level falls of TP 2.3 and TE 1.1 of Vail *et al.*, 1977 (and see also Haq *et al.*, 1988 and Text Figure 14).

Radiometric dating of lavas of the Hebbridean Volcanic Province from Greenland, Scotland and Ireland (see Chapter 6.1) provide ages broadly compatible with the relative stratigraphical position of these tuffs in the North Sea. They are regionally dated as latest Palaeocene - earliest Eocene in age.

Sediments of Late Palaeocene age from onshore U.K. localities do not, however, show any evidence for ash deposition. The earliest Tertiary evidence for this has been located in the basal London Clay (Early Eocene) at Harwich in East Anglia (Elliot, 1971; Knox & Ellison, 1979). This is clearly younger than the main ash phase in the North Sea area and suggests that this may coincide with the period of maximum ash production in the Hebridean Province.

Knox (1979), however, described igneous grains from the Bullhead Member (basal Thanet Formation) at Pegwell Bay. Whilst these *may* have been reworked from the underlying chalk (although if feldspathic this may be unlikely) they may indicate a relationship with the Late Palaeocene volcanic activity in the north.

2.4.Early Eocene Palaeogeography

Though Hebridean volcanic activity continued into the Early Eocene, its effects became noticeably less marked as time progressed into the Early Eocene proper. Separation of Greenland from northwest Europe promoted North Atlantic influences into the area from

the north (and from a lesser extent through the English Channel) and Early Eocene transgressive events were common. The most significant of these led to the deposition of the London Clay and its equivalent offshore units. The "London Clay Sea" was larger in areal extent to the previously described "Thanetian Sea" with the shallower two of the three benthonic foraminiferal biofacies of King, 1983 & 1989 - see above (i.e. the "Inner Sublittoral" and "Outer Sublittoral-Epibathyal" biofacies) increasing in area. The "*Rhabdammina*" biofacies was still largely confined to the central and deeper parts of the North Sea Basin where surface and subsurface marine circulation was still prevented from occurring at greater depth.

The larger extent of the London Clay Sea is demonstrated by the abundance of planktonic foraminifera at certain levels within the London Clay Formation (specifically the so-called "planktonic datum" at the base of Division B1 within magnetochron 24.2 - see Murray *et al.*, 1989). Murray *et al.* (1989) suggest that this planktonic abundance, together with other organisms accompanying them, indicate that water depths of >200m may be envisaged. The present author, however, considers that figure may be somewhat high. The planktonic foraminifera recorded from the London Clay, though they may be abundant, are of simple "globigerine" morphology with keeled and/or thick walled taxa more indicative of deeper waters apparently absent. The palaeogeographic, palaeoclimatic and palaeooceanographic setting during the Early Eocene would appear to have been suitable for the introduction of such morphotypes provided water depths were also suitable. Alex-Sanders (1992 unpublished MS) estimates water depths not exceeding c.110 metres in the London Clay of the Isle of Wight (Hampshire Basin).

The benthonic taxa recorded from the London Clay (see Murray *et al.*, 1989 figs.10.4, 10.5 & 10.10) would appear to have more similarity with those assemblages from the Inner Sublittoral and the Outer Sublittoral biofacies of King, 1983 & 1989 (the latter being approximately equivalent to the Midway Type assemblage of Berggren & Aubert, 1975). King (1989) suggests that water depths for the former were probably between 0-50m and approximately 50-200m for the latter.

Further out into the central parts of the North Sea Basin, typical "*Rhabdammina* biofacies" agglutinated taxa become re-established and dominate microfaunal assemblages. This is coincident with the major eustatic sea level fall during the late Early - early Middle Eocene (base of TE 2.1 of Vail *et al.*, 1977, and see also Haq *et al.*, 1988 and Text Figure 14). A generalised Eocene palaeogeography (after Ziegler, 1990) is shown in Text Figure 6.

Text Figure 6 **Generalised Eocene Palaeogeography (after Ziegler, 1990)**

Encl. 34. Eocene Palaeogeography (main sources: Aren, 1964; Czaszar et al, 1986; Conort, 1980; Gwinner, 1971; Hinsch and Ortlam, 1974; Knox et al., 1981; Krutsch and Lotsch, 1958; Ksiaskiewicz, 1960; Mégnien, 1980b; Pozaryska, 1978; Vinkon, 1988)

2.5. The post-Early Eocene Tertiary

Clastic sedimentation continued throughout the remainder of the Tertiary as subsidence continued. The last structural influence on the area was that of the Alpine Orogenic Phase which took place from Late Cretaceous to Mid-Tertiary times. It was caused by the restriction and eventual closure of Mediterranean Tethys between the European and African continental plates. This had relatively little effect on the North Sea Basin but was more influential towards the southern parts of the area as demonstrated by the almost vertical Palaeogene strata on the Isle of Wight.

In the North Sea Basin, up to 3000m of post-chalk clastic sediments have been deposited, under a variety of depositional settings with the main depocentres around the Central Graben.

3.Localities

Nowhere in Northwest Europe is a complete Palaeocene sequence exposed. This is a major contributory factor to the confusion and controversy over the application of Palaeocene stage names as discussed in Chapter 5. However, many localities can be found displaying parts of the succession throughout Europe.

Palaeocene outcrops were examined from Southeast England and Denmark. Core material was also available from onshore U.K. boreholes. Samples were collected by the author (all U.K. material), the author and Dr. Bruce Tocher (Stevns Klint, Bulbjerg and Lundsgaards Cliff in Denmark).

A map showing the locations of all outcrop sections and boreholes is shown in Text Figure 7.

3.1.Onshore U.K.

The oldest Tertiary strata in the U.K. are the Thanet Sands exposed in Kent. They are best developed in two localities with outcrops at Pegwell Bay and Reculver Cliff near Herne Bay. The Thanet Beds are predominantly fine sands and silts with glauconite and clay seams. They achieve their maximum thickness (about 27 metres) in the eastern part of Kent. They occur (as outcrop and subcrop) roughly within a triangular area bounded by Ramsgate, Epsom and Ipswich (Curry, 1965) and the clay content decreases towards the west. The Thanet Sands rest upon various ages (Coniacian to Campanian) of the Upper Chalk, indicating considerable erosion and planing-off of the chalk. The maximum extent of the Thanet Sea probably reached as far as the Guildford area and then retreated back towards the east laying down the regressive Woolwich and Reading Beds in the process. These beds overlie the Thanet Sands in the east (as the more marine Woolwich Beds) and lie directly on the chalk towards the west of London (as the fluvio-deltaic Reading Beds). These sediments are, in turn, overlain by the Oldhaven (which may be latest Palaeocene in age) and Blackheath Beds of the subsequent Eocene marine transgression.

The Thanet Formation (Thanet Sands) are divided into five "Members" with all but No.3, the Kentish Sands, outcropping at Pegwell Bay:

5. The Reculver Silts
4. The Pegwell Marls
3. The Kentish Sands (NB. in west Kent (near Sittingbourne) only. They are thought to be laterally equivalent to the Pegwell Marls and Reculver Silts and were not studied as part of this project.)
2. The Stourmouth Clays
1. The Bullhead Conglomerate

The Woolwich Beds of Kent progress laterally into the Reading Beds near London and have been divided into six "units" (Hester, 1965; Ellison, 1983):

6. Glauconitic Clay
5. Shelley Clay
4. Laminated Sand
3. Ferruginous Sand
2. Mottled Clay
1. Pebble Beds ("Bottom Bed" of Hester, 1965)

The Pegwell Bay succession in east Kent has been previously described by several authors (Whitaker, 1872; Burrows & Holland, 1897; Haynes, 1954, 1956). The Bullhead Conglomerate, Stourmouth Clays and Pegwell Marls are exposed resting upon frost-shattered chalk of *M.testudinarius* Zone age. The basal conglomerate is composed of poorly sorted, green coated angular flints derived from the underlying chalk which are contained in a glauconitic sandy matrix. This is overlain by several metres of Stourmouth Clays (pale-banded, sandy grey-brown glauconitic clays containing flint grains) and Pegwell Marls (dark grey silty marls and clays). Haynes (1958) recorded no microfossils from the Stourmouth Clays but a diverse microfauna (echinoid spines, fish teeth, sponge spicules, bryozoa, diatoms, ostracods and foraminifera) was recorded from the Pegwell Marls and Reculver Silts.

Haynes' drawing of the Pegwell section (Haynes, 1956, p.81) indicates a (largely complete) section of some 22-23 metres thickness from which he took 54 samples (numbered P1-P54 up section). The section examined by the present author is much less complete. This is probably due to the construction in the 1960s and '70s of hoverport facilities which are now largely disused. The present author was able to sample some 5-6 metres above the base of the Thanet Formation with a 2-3 metre gap before the next *in situ* part of the section which was only c.0.5 metres thick. This included the basal unit of the Thanet Formation (Bullhead Member) and probably all of the Stourmouth Clays, however, it is likely that only part of the Pegwell Marls (probably the lowermost interval) have been sampled in this study (samples PB11 & PB12 herein).

Access to stratigraphically higher sections at Pegwell Bay is difficult due to the construction of the hoverport facilities there. However, a small (about 3 metres) part of the succession can be located behind the hoverport beneath the cliff road. This is comprised of brown silts containing bands of shell debris and large, flat "doggers" of cemented sandstone which can be matched with similar sediments at Reculver and therefore are assigned to the Reculver Silts Member. The vertical interval between these two small sections could not be measured accurately but was probably in the order of 5-10 metres.

The sediments at Reculver Cliff (the Reculver Silts) are easily accessible along the long beach on the north coast of Kent near the village of the same name. The silts are developed in a high cliff face and are composed of grey-brown glauconitic sandy silts becoming less sandy in the lower part. Two parallel rows (about 4-5 metres apart) of hard cemented sandstone "doggers" about 1-2 metres in diameter are also present in the lower levels as well as numerous bands of shell debris. Many doggers have weathered out of the cliff face and much of the beach is covered with them although they can be found *in situ* towards the east of the cliffs near the old Anglo-Saxon fortification. These can probably be linked to the same type of doggers at Pegwell Bay. Above the uppermost dogger band at Reculver (taken by some to mark the top of the Thanet Formation but see Ward, 1978 and below) the sequence becomes more sandy and shelly and eventually more typical of the Woolwich Beds. This junction can also be seen further to the west at the Upnor Pit quarry near Rochester, where massive unconsolidated Thanetian sands are overlain by unidirectionally cross-bedded Woolwich Sands, which are in turn overlain by the pebbly base of the Oldhaven/Blackheath unit.

Haynes (1954-56) in his study of the English Palaeocene collected 20 samples (prefixed "RB") from this locality which he assigned to "subzonule" 4b (see Chapter 2).

Ward (1978) has provided a detailed site report of the succession at Reculver in which he erects and/or modifies several lithostratigraphic units examined there and these units are shown in Table 3.1.

FORMATION/UNIT		NAME	THICK (m)
LONDON CLAY	P	London Clay	36.90
	O	London Clay Basement Bed s.s.	0.60
OLDHAVEN	N	Glauconitic cross-bedded sand	6.00
	M	Glauconitic silty sand	0.75
	L	Basal Pebble Bed	0.30
WOOLWICH & READING	K	Woolwich Marine Beds	5.20
	J	Beltinge Fish Bed	0.40
THANET	I	Unfossiliferous sandy silts	1.25
	H	Sandy silt with plant debris	0.25
	G	G.regulbiensis Bed	1.20
	F	T.parisiensis Bed	0.60
	E	A.tenera Bed	1.00
	D	P.remensis Bed	3.20
	C	A.morrisi Bed	2.10
	B	Reculver Tabular Band	0.20
	A	E.cuneatus Bed	7.75

TABLE 3.1: Lithostratigraphic Terminology of the Lower Tertiary deposits of Herne Bay, Kent (after Ward, 1978). Thicknesses given are maximum values.

Ward also discusses the history of the placement of the Thanet / Woolwich & Reading Formation boundary and concludes that the lithological differences between Units I and J with flint pebbles, green-coated flints and sharks teeth of Unit J indicating a major sedimentary discontinuity, warrant placement there. He equates the Beltinge Fish Bed (Unit J) as the lateral equivalent of the Woolwich & Reading Basal Pebble Bed (Woolwich Bottom Bed of Gurr, 1963). He also lists over 120 species of foraminifera recovered from this locality (after Haynes, 1956, 1958; Wood & Haynes, 1957 and Haynes & El-Naggar, 1964).

The Thanet and Woolwich Beds were also sampled from core material provided by the British Geological Survey from a borehole at Wormingford Mere. This borehole penetrated a thickness of 33.0 metres of Tertiary sediments before encountering Cretaceous chalks. Of this 20.85 metres were recorded as Palaeocene (9.35m of "Woolwich and Reading Beds" overlying 11.5m of "Thanet Beds"). The Woolwich Beds were logged as "interbedded mottled purplish clay with "race" and greenish-grey silt", with the lower 1.5m being glauconite rich. The Thanet Beds were described as "bioturbated grey fine-grained sand with occasional beds of glauconite-mottled clay, particularly in the bottom 1 metre".

Key to Text Figure 7 (Localities) overleaf.

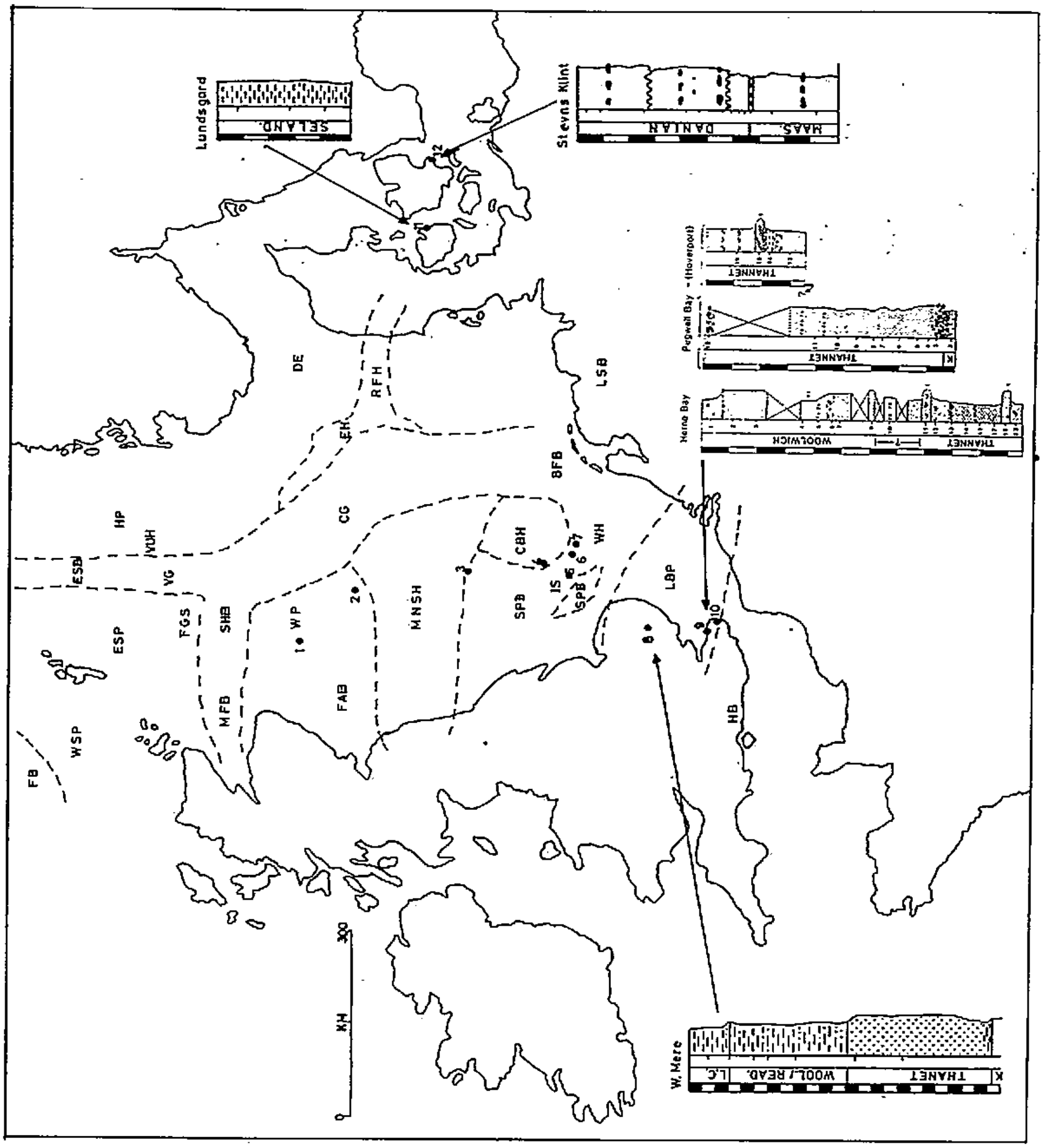
Localities (vertical scale bars = 1.00m)

1.	21/26-1D	8.	Wormingford Mere B.G.S. borehole
2.	29/25-1	9.	Reculver, Herne Bay, UK
3.	44/2-1	10.	Pegwell Bay, UK
4.	49/10-1	11.	Lundsgaards Cliff, Denmark
5.	49/22-2	12.	Stevns Klint, Denmark
6.	49/24-2, -3, -4		
7.	49/25-1, -2		

"North Sea" Structural Elements;

BFB	Broad Fourteens Basin	LSB	Lower Saxony Basin
CBH	Cleaver Bank High	MFB	Moray Firth Basin
CG	Central Graben	MNSH	Mid North Sea High
DE	Danish Embayment	RFH	Ringkøbing Fyn High
EH	Egersund High	SHB	South Halibut Basin
ESB	East Shetland Basin	SPB	Sole Pit Basin
ESP	East Shetland Platform	UH	Utsira High
FAB	Forties Approaches Basin	VG	Viking Graben
FB	Faeroe Basin	VUH	Vestland Utsira High
FGS	Fladen Ground Spur	WH	Winterton High
HB	Hampshire Basin	WP	Western Platform
HP	Horda Platform	WSP	West Shetland Platform
IS	Inde Shelf		
LBP	London Brabant Platform		

Text Figure 7 **Localities of sections and wells used in this study**



3.2.Onshore Denmark

The majority of localities studied in Denmark covered the Late Cretaceous - Danian interval developed in carbonate facies. Several Cretaceous-Tertiary boundary sections were examined and sampled. These included Bulbjerg, Nye Cliff, Kjolby Gaard and Dania Quarry in Jutland and Stevns Klint on Zealand. A "Selandian" (Late Palaeocene) sequence of (Kerteminde) marls were also examined and sampled at Ludsgaard's Cliff on the island of Fyn.

Nye Cliff and Kjolby Gaard are relatively small inland road/bank-side exposures that were once sea cliffs. They offer a reasonable vertical succession but little lateral extent, a feature better developed at the Bulbjerg coastal section and, spectacularly, at Stevns Klint in the coastal cliffs. The comparable section at Dania Quarry is now largely obscured due to the quarry workings.

The Stevns Klint locality of eastern Zealand provides the most complete and accessible Cretaceous - Tertiary boundary sequence and laterally extensive Danian carbonates which outcrop and are almost untilted along the entire coastline. They display large bryozoan bioherm mound structures with flint bands picking out large-scale cross beds. The Fish-Clay layer is also well developed here which lies between clean, white, flinty Maastrichtian chalks and bryozoan-rich limestones of the Danian. This section is arguably one of the most important worldwide exposures of this important stratigraphic boundary and consequently the amount of literature pertaining to it is extraordinary (e.g. see Birkelund & Bromley, 1979 for a small sample). In view of the importance of this section, a schematic diagram of the locality is shown in Text Figure 8.

The Maastrichtian chalk at Stevns Klint is represented by thicknesses of up to 35m along the entire cliff section. The lower 5-10m of the sequence (not sampled here) is comprised of bryozoan-rich chalk, deposited in low mounds as evidenced by undulating flint bands. The next 20m or so is represented by horizontally bedded chalk with an apparently lower fossil content and a high density of *Zoophycos* burrows (Surlyk, 1979). A prominent flint horizon (which can be traced along the entire cliff section) occurs near the top of this "White Chalk" unit, the top of which is marked by an omission surface less than a metre above the flint band. Above this surface lies c.3-4m of bryozoan-rich limestones ("Bryozoan Chalk") which were deposited in low, asymmetric biohermal mounds, each of which overlaps the next to the south. These bioherms are picked-out by flint bands which are mainly found to lie along the less-steep northern flank. *Thalassinoides* burrows are common.

The surface of the uppermost "Bryozoan Chalk" forms broad shallow basins and the apexes of the bioherms have all been "planed off" by a burrowed hardground at the top of the "Cerithium Limestone" (see below).

Within these basins occurs the so-called "Fish Clay" layer which actually consists of 4 individual sub-layers (Christensen *et al.*, 1973). The Fish Clay can achieve thicknesses of up to 35cm in the deeper parts of the "basins" (not observed up to this thickness here), although it wedges out completely towards the "basin" margins. The 4 layers (+1 each above and below) are described as follows (after Christensen *et al.*, 1973):

Bed VI	Cerithium Limestone	Limestone, calcareous silt, white, often slightly yellow, devoid of bryozoans but with abundant *Thalassinoides* burrows
Bed V	Fish Clay	Marl, veined and streaked, light grey, containing fragments of white chalk (5-7cm)
Bed IV	Fish Clay	Marl, streaked, black to light grey (3-5cm)
Bed III	Fish Clay	Marl, silty, black, with pyrite concretions (2cm)
Bed II	Fish Clay	Marl, layered, grey (1-2cm)
Bed I	Bryozoan Chalk	Chalk, calcareous silt, whiteish grey, abundant bryozoans

To say that the scientific and popular interest generated by this important unit (given its stratigraphical position) is inversely proportional to its thickness would be an understatement. As mentioned above and below, it is not within the scope of this thesis to examine every hypothesis proposed *vis a vis* the Cretaceous - Tertiary boundary and the cause(s) of extinctions thereof. Nevertheless, some mention needs to be made here of the current opinions with regard to the biostratigraphy of the Fish Clay.

Unfortunately, planktonic foraminifera are extremely rare in the Fish Clay and doubts as to their status (*in situ* or reworked) are many. No specific mention of planktonic foraminifera recorded from the Fish Clay is noted by (for example) Hofker (1960), Berggren (1962a) and Bang (1969, 1971 & 1979).

Perch-Nielsen (1979) records a nannofloral assemblage from the Fish Clay which differs only slightly from that recorded in the underlying Maastrichtian chalk. However, two taxa

(*Thoracosphaera* spp. and *Bianolithus sparsus*) are said not to be found in the underlying Maastrichtian chalk and thus apparently confer a Danian age upon the Fish Clay. Perch-Nielsen also records the persistence of some nannofloral genera across the C/T boundary which she regards not to be reworked (although the bulk of the other forms recorded from the Fish Clay are indeed regarded as such).

A study of the palynoflora of the Fish Clay of Denmark and Southern Sweden by Hultberg (1985) yielded a highly detailed palynostratigraphy of this enigmatic unit. The Cretaceous / Tertiary transition is even less well marked by extinctions within the palynoflora than the nannofossils. Abundances of palynomorphs do, however, increase between the underlying Maastrichtian chalk and the overlying Fish Clay. Hultberg therefore suggests that the Fish Clay palynofloras are primary and not reworked. He notes the following palynofloras in each of the 4 Fish Clay subunits of Christensen *et al.*, 1973:

Bed V	barren of dinoflagellates
Bed IV	assemblage dominated (70%) by *M.druggii*
Bed III	monospecific assemblages of *M.druggii*
Bed II	Maastrichtian assemblages dominated by *P.grallator*

The Fish Clay from Dania and Kjolby Gaard, however, yielded well developed Danian palynofloras, the composition of which indicates deposition under normal marine conditions in western Denmark.

Hultberg concluded that the age of this unit is biostratigraphically older in eastern Denmark (e.g. Stevns Klint) than in western Denmark (e.g. Kjolby Gaard) i.e. that it is diachronous. In fact, due to the recovery of no Danian palynological taxa from Stevns Klint, he concludes that the Fish Clay unit at Stevns Klint is actually latest Maastrichtian in age as opposed to earliest Palaeocene. This is supported somewhat by foraminiferal evidence quoted by Hultberg and also by this study.

Measurements of the palynofloral components of these assemblages suggest that deposition of most of the Fish Clay at Stevns Klint may have taken place under low salinity or brackish conditions (Hultberg, 1985). The fine laminations of Bed IV and the pyrite nodules of Bed III indicate that conditions may have been euxinic, at least during the deposition of the lower part of the Fish Clay (Surlyk, 1979).

These conclusions throw questions on the so-called “global impact extinction hypothesis” proposed for the end-Cretaceous mass extinction event by Alvarez *et al.* (1980) and others. Proponents of this hypothesis assume global synchroneity between different Cretaceous - Tertiary boundary layers containing Iridium peaks as the source of this platinum group

metal is thought to have been an extraterrestrial body which impacted on the Earth's surface.

At Stevns Klint, the Fish Clay is overlain (at least within the Bryozoan Chalk bioherm "basins") by a c.0.5m thick unit - the "Cerithium Limestone". This unit is intensively burrowed by *Thalassinoides* and is often yellow in colour. The top of the Cerathium Limestone has been eroded (probably submarine in origin and followed by early diagenetic cementation down to a depth of c.30cm (Surlyk, 1979)) - an event which also "planed off" the crests of the intervening Maastrichtian Chalk bioherms. This hardground contains a diverse macrofauna including the lower Danian echinoid *Brissopneustes danicus*.

This hardground forms the base for a thick sequence of bryozoan-rich limestones ("Bryozoan Limestone") which display similar bioherm features to the Maastrichtian Bryozoan Chalk below. However, these bioherms are much larger (varying from c.8-c.20m high) and have more abundant and continuous flint bands which pick out the bioherm development. The north - south overlap by successive bioherms is still apparent and the bioherms themselves were probably originally formed by upcurrent growth of bryozoan mounds (Thomsen, 1976).

The biohermal development within the Bryozoan Chalks (Maastrichtian) and the Bryozoan Limestone (Danian) at Stevns Klint indicate deposition under the influence of a dominantly unidirectional water flow (north to south), below normal wave base (Bromley, 1979). Hakansson *et al.* (1974) considers the Bryozoan Chalk to have been deposited around the lower limit of light penetration (i.e. c.150m), whilst the features displayed in the Bryozoan Limestone (see Bromley, 1979) suggest possibly shallower waters (e.g. up to c.80m (Thomsen, 1976)) during the earliest Palaeocene.

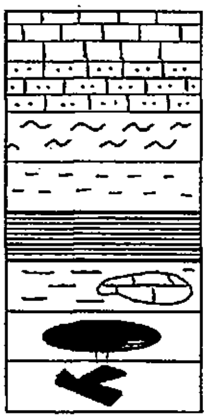
The Bulbjerg section of northern Jutland also displays the bioherm development but does not contain a K/T boundary layer. These carbonates are thought to be of younger Danian age than those of Stevns Klint.

Key to Text Figure 8 (Stevns Klint) overleaf.

(vertical scale bars = 1.50m)

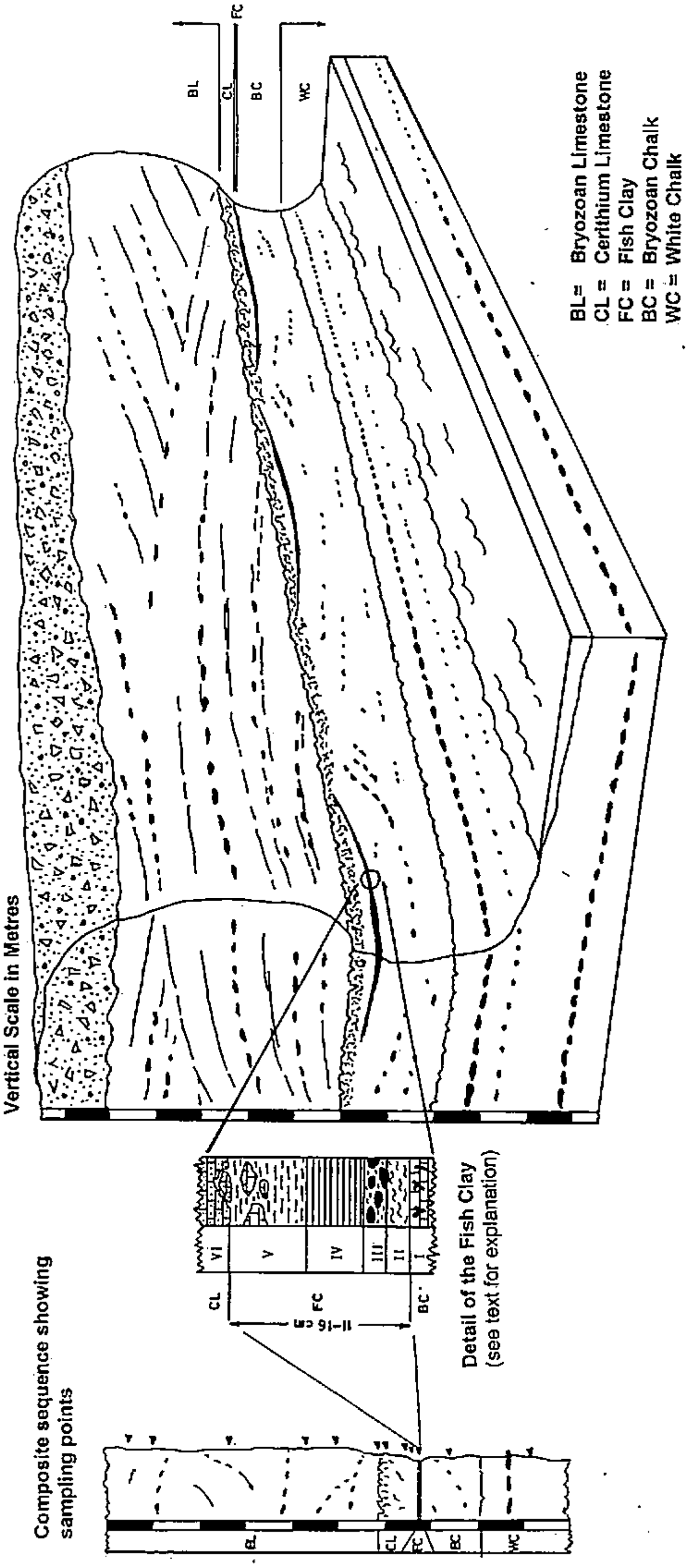
BL	Bryozoan Limestone	
CL	Cerithium Limestone	Bed VI (part) of Christensen *et al.*, 1973
FC	Fish Clay	Beds II - V of Christensen *et al.*, 1973
BC	Bryozoan Chalk	Bed I of Christensen *et al.*, 1973.
WC	White Chalk	

Details of Fish Clay lithologies:



Chalk; whiteish grey
Limestone; silty, white - often slightly yellow
Marl; layered, grey
Marl; silty, black
Marl; streaked, black - light grey
Marl; veined & streaked, light grey w/ fragments of white chalk
Pyrite nodules
Bryozoa

Text Figure 8 **The Stevns Klint (Denmark) locality; schematic**



3.3.Offshore (North Sea)

Samples were examined from 9 wells drilled by Shell (U.K.) Exploration and Production Ltd. during the 1960's and early 1970's. Seven of these wells are located between 53° and 54° North in what is termed the Southern North Sea with the remaining two drilled further northward into the Central North Sea. Some pertinent data for each well is give in Table 3.2.

All the wells are situated on structural "highs" or platforms as opposed to basinal depocentres.

Wells 21/26-1D and 29/25-1 are located some way onto the Western Platform which borders the west and southwestern edge of the Central Graben. Well 44/2-1 is located on the North Dogger Shelf, well to the southwest of the Central Graben. Wells 49/10-1 and 49/20-2 are located on the Cleaver Basin High and the remainder of the wells (49/24-2,3 & 4 and 49/25-2) are situated on the Indefatigable Shelf.

WELL	LAT/ LONG	YEAR COMP	WATER DEPTH (ft)	K.B. ELEV. (ft)	INTERVAL ANALYSED	SAMPLE TYPES
21/26-1D	57°05'N 00°05'E	1968	289	84	2660'-3650'	Cuttings
29/25-1	56°20'N 01°50'E	1970	271	78	5800'-6156'	Cuttings & SWCs
44/2-1	54°50'N 02°25'E	1965	82	86	2730'-3090'	Cuttings
49/10-1	53°45'N 02°40'E	1971	122	81	2820'-3030'	Cuttings
49/20-2	53°27'N 02°58'E	1971	103	91	2490'-2850'	Cuttings
49/24-2	53°10'N 02°40'E	1968	102	100	1860'-2220'	Cuttings
49/24-3	53°19'N 02°45'E	1969	103	96	1700'-1920'	Cuttings
49/24-4	53°19'N 02°42'E	1970	107	100	1460'-1790'	Cuttings
49/25-2	53°12'N 02°51'E	1970	97	97	2030'-2780'	Cuttings

TABLE 3.2: Supplementary data for wells used in this study.

4.Sampling and Techniques

4.1.Sample Quality and its Effect on Results

Geologists collecting samples from outcrops are able to exert great control on sample quality. Precise locations can be pinpointed, required amounts obtained and contamination minimised. It is also possible to examine material in 3 dimensions. Micropalaeontological analysis using this quality of material can be very comprehensive with quite high resolution work possible. Also many statistical packages can be applied to such data for biostratigraphic, taxonomic and palaeoenvironmental studies. Samples collected from onshore localities visited by the author were taken bearing these points in mind. Scaled schematic logs of the samples sections are included with the palaeontological distribution charts in the Appendix at the end of this thesis.

Unfortunately, the same accuracy and precision cannot be expected when using samples obtained by rotary drilling (commonly known as "ditch cuttings"). The process by which these samples are obtained is described briefly below and shown diagrammatically in Text Figure 9.

The main factors influencing the quality of samples obtained at the well head are:

- Drilling Fluid (or "Mud")
- Drilling Practices (Rate of penetration, bit type etc.)
- Human factors

Of these, the drilling fluid, or mud, is probably the most important. This mud has several functions in the drilling process not least of which is to control the subsurface geopressures encountered at depth in an open borehole. To counteract these pressures (to fail would result in blowout) the mud needs to have sufficient MUD WEIGHT (i.e. density). The control of the mud weight is critical in drilling. Too high a mud weight (an "overbalanced" situation) would result in the borehole fluids invading and possibly damaging the formation being drilled. Also high weight muds are expensive and impair efficient drilling. Too low a mud weight ("underbalanced") would not be sufficient to restrain the subsurface geopressure and a blowout would probably result. Ideally, the mud weight in a borehole being drilled would exactly counteract the subsurface geopressure encountered. However, this is not in itself strong enough to prevent the walls of the borehole from sloughing off and falling into the borehole itself, a process known as caving which has serious implications for micropalaeontological sample quality (see below).

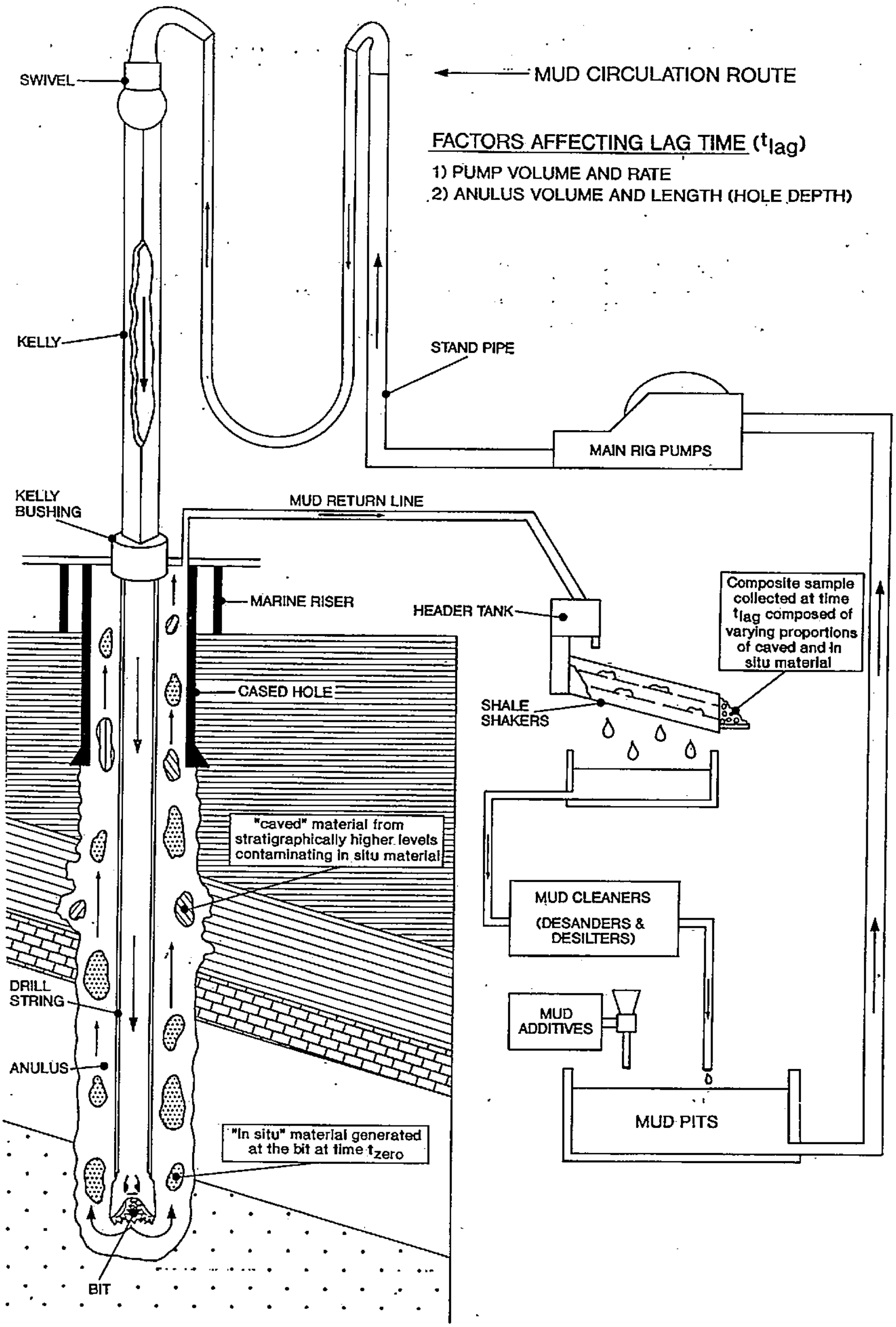
Should drilling also cease for any reason, the mud should be sufficiently viscous enough to hold the cuttings suspended in the borehole. Prolonged periods of stagnation can result in cuttings "settling out" with mixing of cuttings generated from different depths.

To assist in high rates of penetration (and hence economical drilling), bit technology has advanced to Turbine Drilling (mud flow through the drill pipe which drives a turbine motor behind the bit in addition to the rotary speed applied to the drill string as a whole) and the use of "Stratopax" type bits. These bits tend to "chew out" ditch cuttings rather than break them up as would a normal roller-cone bit, and microfossils can often be damaged by this process, sometimes being rendered unidentifiable.

Text Figure 9 shows that there is a time-lag between the generation of cuttings at the bit and their appearance at the surface over the "shale shakers". This "lag-time" can be calculated and is a function of borehole geometry, hole depth and rate of mud pumping or can be measured directly by the introduction of a detectable substance into the system (e.g. acetylene) and the timing of its reappearance at the surface. Either of these methods can only be at best an approximation and hence the certainty that a sample is in fact representative of the interval it is supposed to be from, is largely open to question. The concept of "INTERVAL SAMPLES" is also raised here. The lag-time is started when the bit has "cut" the rock at the required depth. After the expiry of the lag-time, the cuttings from that depth will, hopefully, be at the surface but also along with the cuttings from the interval immediately above, proceeding from the previous sample taken. Also the amount of sample available to the micropalaeontologist seldom exceeds about 20 grams which may not be totally representative of a (sometimes) 40 foot interval.

The rate of penetration of the formation has an indirect bearing upon sample quality. Part of the job of the "mudlogging geologist" on a rig is to collect the samples at the right time when they appear at the surface over the shale shakers. For samples at 30 foot intervals (usual for the North Sea Tertiary) at normal rates of penetration, this can mean collecting and describing one sample every ten minutes. Under high penetration rates this can often be reduced to one every five minutes or less, a situation that the author has experienced at first hand. The potential for errors at these rates.is high and samples can be mis-caught or even missed altogether.

Text Figure 9 Borehole sample collection at wellsite during rotary drilling



The practical rôle of caving upon sample quality in boreholes cannot be overstressed. The effect of caving is to introduce rocks (and hence microfossils) of a stratigraphically younger position into approximately *in situ* samples of "known" position. In terms of biostratigraphy this will artificially extend the life-range of a species downwards (i.e. older) and therefore mask the true evolutionary appearance of that species in a drilled stratigraphic succession. Hence in offshore or indeed "industrial" biostratigraphy, zonation schemes based on the highest occurrences of species (i.e. their extinctions) are preferred to the more conventional and scientifically correct method whereby lowest (i.e. evolutionary) occurrences are used (see Chapter 7). Extinction events can sometimes be misleading but at least are not affected by problems of caving unless the species in question is particularly rare in the area.

Two methods of downhole sampling are, however, not subject to caving problems. Cores, where taken, provide samples which are uncontaminated and can be pinpointed accurately in a depth succession. Sidewall Cores, though smaller, also provide accuracy. Unfortunately these methods of sample collection are time consuming and expensive and are normally only done over intervals of great economic rather than academic interest in a well. In this study, sidewall core material was available from well 29/25-1. The wells drilled in the Southern North Sea were targeted on the Permian gas play and thus core sampling in the Tertiary was not required.

Core material was available however from the two British Geological Survey boreholes at Bures and Wormingford Mere and was examined in this study. These were 2" (5.0 cm) (diameter) cores and were sampled at approximately 1 metre intervals taking 200-500 grams of material per sample.

4.2.Processing Techniques

Two types of samples were used in this study, those collected by the author from onshore outcrop localities and B.G.S. core material and ditch cuttings samples provided by Shell (U.K.) Exploration and Production Ltd. from North Sea Boreholes. The most important physical difference between the two types being their size - approximately 0.5 - 1.0 Kg for the former and less than 0.002 Kg for the latter. However, processing methods were similar for both types.

The majority of samples were from soft un- or semiconsolidated sediments which required very little washing to break them down. Samples from the chalk localities or intervals on the other hand were often well cemented and required crushing under water in a large mortar until a coarse sand-size slurry was obtained which was then processed in the same way as the softer samples, described below.

1) The microfossils were released from the sediment by washing over a 75 µm aperture sieve by a gentle water jet. This also removed all clay size material which would hinder picking.

2) The residue was transferred to a filter funnel where excess water was allowed to drain off and the filtrate dried in an oven at 60°C.

3) The dried residue was then labelled and stored in preparation for picking.

4) The picking process required the splitting of the sample into discrete size fractions for ease of examination. This involved passing the sample through a nest of sieves of 500µm, 250µm and 125µm aperture size resulting in 4 size fractions.

5) Each size fraction was examined microscopically on a 9cm x 5cm tray and any microfossils found removed using a size 00 paint brush and placed onto a 32-grid micropalaeontological assemblage slide coated in a dilute solution of gum tragacanth.

6) A maximum of 300 specimens per sample was taken although the ditch cuttings samples were picked totally, irrespective of numbers recovered. Any sample requiring an examination of ten trays of residue without finding any microfossils was deemed to be barren.

7) Specimens selected for illustration were mounted onto copper stubs, gold coated, and photographed on a Jeol T20 Scanning Electron Microscope in the E.M. Unit, University of Plymouth.

5.Chronostratigraphy

5.1.Introduction

Rapid vertical and lateral lithological variation of facies, language differences and personal philosophies of workers have resulted in a plethora of various chronostratigraphic stage names which cover the interval from Late Cretaceous to Early Tertiary times. A review of Palaeocene chronostratigraphy is essentially a review of the literature of which a full review is beyond the scope of this thesis. Most of the stage names given below have only very limited local application and are only retained for their parochial value.

5.2.The Cretaceous

As only a few samples in this project were obtained from Cretaceous (Maastrichtian) strata, brief remarks only will be given for that stage.

The Cretaceous was first formally subdivided by d'Orbigny (1842) into a six-fold division comprising Neocomian, Aptian, Albian, Cenomanian, Turonian and Senonian stages. Desor (1847) later introduced the term Danian for the youngest unit of the Cretaceous above the Senonian (see below). Two years later, the term "Maestrichtian" (French spelling) was introduced by Dumont (1849) as the youngest substage of the Senonian when he described the Calcaire Grossier exposed near the Dutch town of Maastricht.

5.2.1.The Maastrichtian

The type section sequence exposed in the quarry at Maastricht (proposed by Uhlenbroek, 1912 and refined by Franken, 1947) is:

Md
Mc Craie de Maastricht (Tuff Chalk)
Mb
Ma

Cr4
Cr3c
Cr3y Craie de Gulpen (Gulpen Chalk)
Cr3b
Cr3a

Van der Heide (1954) maintained that Dumont's definition included only the Tuff Chalk relegating the Gulpen Chalk to the Senonian. Voigt (1956) argued otherwise and reinstated the Gulpen Chalk to the Maastrichtian. Evidently the original Maastrichtian was poorly defined and its precise meaning still recently debated. Ball (1985) indicates that confusion over the stage limits stems from the fact that the type section is a warm water detrital facies which bears little relation to the more typical white chalk facies of northern Europe. Palaeontological studies fared little better with early ammonite workers reaching conflicting conclusions (see Grossouvre, 1897 and 1901; Arnaud, 1897). Belemnites proved more successful and the first evolutionary appearance (i.e. lowest occurrence) of *Belemnitella lanceolata* now marks the base of the Maastrichtian.

5.3.The Palaeocene

The term "Palaeocene" was introduced by Schimper in 1874 to distinguish the lowest part of the Tertiary system which up until then was included as the lowest part of the Eocene. He used the term when describing the "Traertin de Sezanne" in the eastern part of the Paris Basin and considered the floral content was sufficient to distinguish it from the younger Eocene and older Upper Cretaceous and to warrant a new stage name. Also assigned to this new stage were the continental conglomerates of "Meudon" and "Cernay", characterised by their mammalian fossils. It was perhaps unfortunate that Schimper chose a continental/non-marine sequence on which to base his new stage. Correlation with adjacent marine deposits was just about impossible and has led to much controversy surrounding its position. Ironically, the French themselves have taken the most pessimistic view of the stage and even as relatively recently as 1957, advocated its removal from the geological column (Magnin, 1957). Even in the United States, it was only formally recognised by the U.S. Geological Survey in 1939. Most support for the new stage came from Scandinavia and the Soviet Union.

Many sediments have been excluded from the Palaeocene because of the poor initial definition and the "Pisolitic Limestones" of Laversines and Vigny were only comparatively recently elevated from the Late Cretaceous to the Tertiary and proved to be equivalent to the "Tuffeau de Ciply" in Belgium (Damotte & Feugueur, 1963). Hence the Palaeocene of the Paris Basin includes various rock-units between Upper Cretaceous chalks and the basal Eocene but with their upper and lower limits uncertain. Even relatively recently there is still some uncertainty as to whether or not the flora Schimper mentions from the "Lignites de Soissonais" actually came from these beds at all or from the younger overlying Cuisian (Lower Eocene) sandstones (Berggren, 1965).

The first study of Palaeocene microfaunas was made by Von Koenen (1885) with a foraminiferal investigation of the glauconitic sediments at Copenhagen and showed that they were more comparable with the Palaeocene and not the Cretaceous as was previously thought. He correlated them with the Bracheaux Sands of France as the younger part of the Middle Palaeocene, a correlation which has stood until today.

To add further confusion, even before Schimper's introduction of "Palaeocene" several other stage names were erected to describe various segments of the interval between the Late Cretaceous and Early Eocene: The Landenian (1839); Danian (1846); Heersian (1851); Montian (1868) and Thanetian (1873). Also, others were introduced subsequently: Sparnacian (1877); Seelandian (= Selandian of some) (1924); Eysdenian (1931); Dano-Montian (1949) and Ilerdian (1960).

The type sections for all of the above are located over a wide expanse of Europe and were set up by different authors for different sedimentary sequences formed by a variety of environments ranging from continental through lagoonal, brackish and estuarine to shallow and deep marine. Given this, the possible combination of terms to describe the Palaeocene seems endless. El-Naggar writes (1966 p.24)...

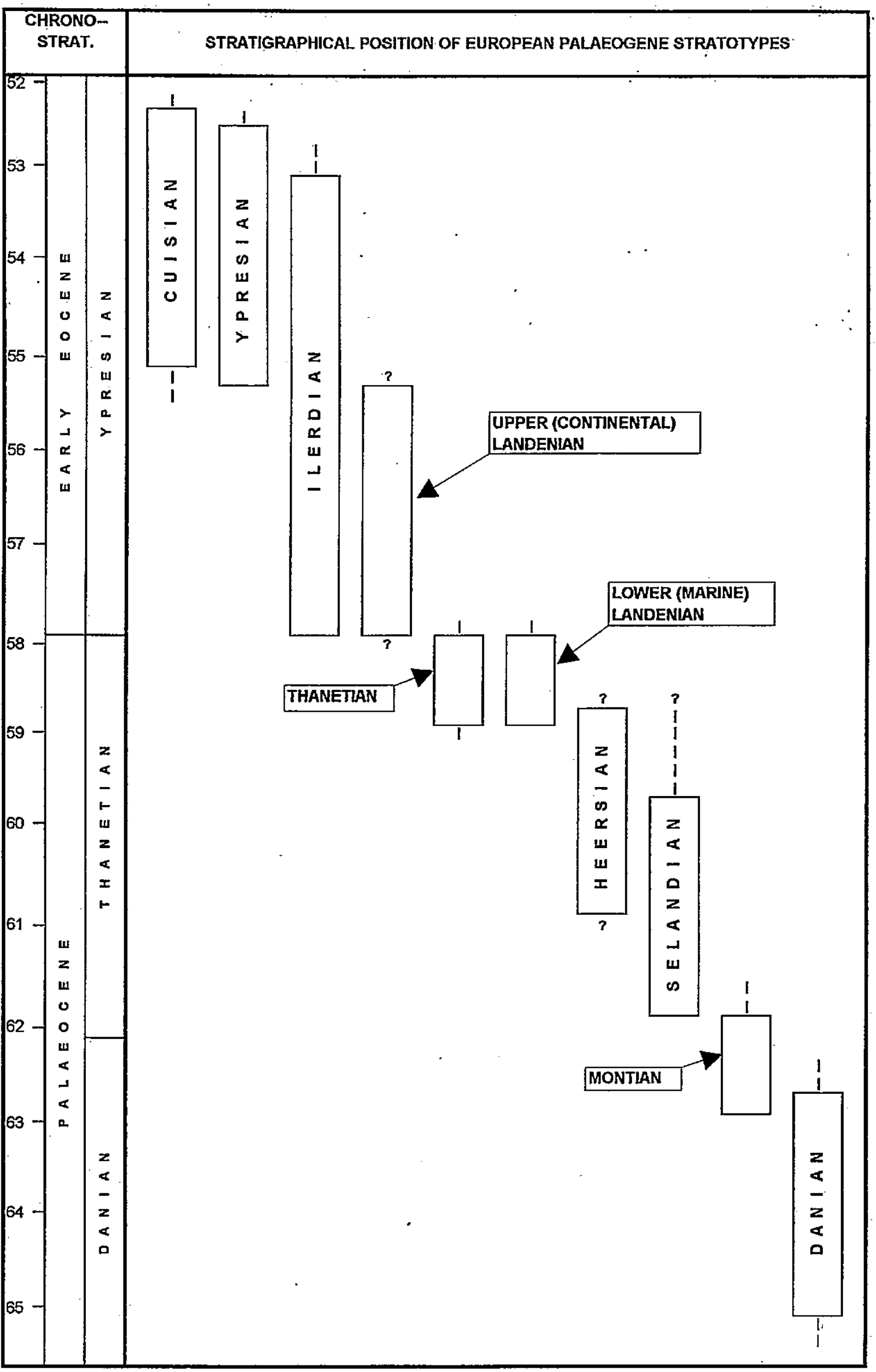
> *"Thus, while the Palaeocene in the Paris Basin was regarded as including the Thanetian and Sparnacian; the Montian, Thanetian and Sparnacian; the Montian and Thanetian; or the Thanetian alone, it was taken to include the Montian and Landenian in southern Belgium; the Montian, Heersian (with or without the Infra-Heersian) and Landenian in northeastern Belgium and Holland; the Thanetian with or without the Woolwich and Reading Beds in England; the Selandian, Thanetian and Landenian in Sweden and Denmark, and any further combination of these plus or minus the Danian."*

This statement does not include the various terms set up in the Soviet Union i.e. the "Inkermanian" (=Montian) and "Kachaian" (=Thanetian) stages which excludes the Danian from the Palaeocene (U.S.S.R. Permanent Stratigraphic Commission for the Palaeocene, 1963). Neither does it include the American "Midway", "Sabine" and "Wilcox" stages. Other names were introduced which encompassed several of the stages mentioned above i.e. the Suessonian (Landenian, Sparnacian and Cuisian) and Garumnian (Danian and Montian). These were fortunately dropped shortly after their introduction.

The question of the validity of the term "Middle" Palaeocene is also problematic. On the European mainland, stratigraphic stages such as Selandian and Montian have often been termed Middle Palaeocene, with the Late Palaeocene being represented by the Landenian stage. In low-latitude continuous marine sequences, almost all workers delineate a Middle Palaeocene which spans planktonic foraminiferal Zones P2-P4 (see Chapter 7). In the North Sea region however, the Palaeocene is simply divided two-fold with the junction between the Early and Late Palaeocene being placed at the top of Zone P2.

The relative stratigraphical positions of several of the stratotypes mentioned above are shown in Text Figure 10.

Text Figure 10: Stratigraphical Setting of several European Palaeogene Stratotypes



6.Geophysical, Litho- & Sequence Stratigraphy

6.1.Radiometric Time Scale

Standard Cenozoic radiometric time scales have been erected by Berggren & Van Couvering (1974); and Hardenbol & Berggren (1978) with a review by Harland *et al.* (1982) which is used here. The percentage error cited by Harland *et al.* is + or - 2.7 Ma at 60 Mybp to about + or - 12 Ma at 500 Mybp. This data is shown below in Table 6.1.

TERTIARY {63.0} 65.0	EOCENE {16.9} 54.9	50.5 Early {4.4}
	54.9 PALAEOCENE {10.1} 65.0	Late {5.3} 60.2
		Early {4.8}
CRETACEOUS {79.0}	MAASTRICHTIAN {8.0}	

TABLE 6.1:Radiometric Time Scale for the Maastrichtian - Early Eocene Interval (after Harland *et al.* 1982).
Figures in millions of years absolute age and {duration}.

Generally, radiometric age determinations are made from the analyses of radioactive elements and their daughter products after decay in igneous rocks although similar methods can date glauconite grains in sediments.

The nearest igneous complex in both age and proximity to Northwest Europe during Early Tertiary times is the so-called Hebridean Volcanic Province - a series of plateau basalts formed during the separation of NW Europe and Greenland (see Chapter 2). These basalts (found in Greenland) have been dated as 50.0 Mybp + or - 1.4 (Early Eocene) by Odin & Mitchell (1983). Associated intrusions in the U.K. are thought to be no more than two million years younger (Mitchell & Reen, 1973).

The Potassium-Argon method of age dating can also be used in glauconite grain age determinations. Glauconite, a common authigenic constituent of marine sediments, is basically a muscovite mica lattice with Al and Fe/Mg within that lattice. Glauconite dates from Europe (summarised in Hardenbol & Berggren, 1978 from various authors) are : Bracklesham Beds, U.K. 49.4 Ma (earliest Middle Eocene); "Cuisian" of Paris, 51.3 Ma

(Early Eocene); "Thanetian" of Paris 53.6 Ma (Earliest Eocene); "Thanetian" of U.K., 57.0 Ma (Late Palaeocene); Gelinden Marls, Belgium, 57.1 (Late Palaeocene).

6.2. Magnetostratigraphy

The principles of magnetostratigraphy are well established and need not be repeated here. Polarity intervals vary in length from 0.01 Ma to several 10's Ma. A polarity "chron" is a period of dominantly one type (normal or reversed) of interval or another and a numerical convention has been established for the naming of magnetostratigraphic intervals from the Latest Cretaceous to the present day. Magnetic anomalies begin with the most recent at the Mid-Ocean-Ridges and are numbered "1". This then carries on to anomaly "32" an anomaly dated as approximately Early Maastrichtian in age.

The oldest Tertiary magnetozone occurring in the U.K. is termed the Thanet Magnetozone. It is the lowest of 8 stratigraphically distinct "normal" polarity magnetozones in an otherwise "reversed" polarity sequence in the Lower Palaeogene formations of the London and Hampshire Basins (Townsend & Hailwood, 1985). It occurs in the Thanet Sands of Pegwell Bay and Aubry, Hailwood & Townsend (1986) have attempted an integration with the calcareous nannofossil zonation of Martini (1971). Calcareous nannoplankton assemblages occur in the younger part of the Thanet Sands at Herne Bay (Bramlette & Sulivan, 1961; Hay & Mohler, 1967). They were assigned to Zone NP8 by Martini (1971) with Aubry (1983) then assigning the Lower Thanet Beds (Pegwell Bay) to Zone NP7 or older, i.e. the Thanet Magnetozone is equivalent to Zones NP6-7 and possibly 8. The "chron" associated with Zone NP6 is numbered "C26N", marine anomaly 26 (Townsend, 1984; Shackleton *et al.*, 1984) taken from D.S.D.P. results. Onshore sections in the southern Alps have also provided evidence to confirm this (Lowrie *et al.*, 1982; Alvarez & Lowrie, 1984). These magnetochronozones are shown on a diagram in the chapter on Sequence Stratigraphy (Text Figure 14).

A second magnetozone has also been recognised in the Oldhaven Formation at Herne Bay, specifically from the volcanic ash-bearing Herne Bay Member of the Oldhaven Formation. Unfortunately the Herne Bay Member contains no age-diagnostic fossils although it is over- and underlain by sediments of *A.hypercanthum* dinoflagellate Zone age (Knox, Harland & King, 1983) and can therefore be assigned to this Zone. Costa & Muller (1978) correlate the *A.hypercanthum* Zone to nannofossil Zone NP9 and Knox (1984) correlates it with Zone NP10. Aubry, Hailwood & Townsend (1986) favour this younger age and have concluded the Oldhaven Magnetozone to be a short period of normal polarity which occurred during the reversed C24R chron owing its recording and preservation to the locally high sedimentation rates of the Oldhaven Beds.

6.3. Lithostratigraphy

Most onshore Palaeocene sections in Northwest Europe are of a highly variable character and lithological similarities do not appear to extend over large distances and are useful only at local level. However, more complete Early Tertiary sequences with greater lateral persistency are found offshore and standard lithostratigraphic schemes are available.

More recently, a major synthesis of the Northwest European Tertiary Basin has been published (Vinken (compiler), 1988). Knox *et al.* (in Vinken, 1988) have described the lithostratigraphic succession in the London Basin and East Anglia. They describe an upward sequence of Thanet Beds, Woolwich & Reading Beds, Oldhaven Beds and the London Clay Formation. All of these are dated as Late Palaeocene except the London Clay Formation of which only the basal Harwich Member (unit A1) is given a tentative latest Palaeocene age.

Late Cretaceous - Tertiary lithostratigraphy (Rhys, 1974, 1975) is much simplified in the Southern North Sea because of the lesser economic importance of this stratigraphic interval in this area. However, in the Central and Northern North Sea areas, a fairly detailed scheme (Deegan & Scull, 1977) is in use. A standard lithostratigraphy for the Dutch Sector of the North Sea (NAM and RGD, 1980) has also been published.

Knox *et al.* (in Vinken, 1988) also describe the lithostratigraphy of Quadrant 22 (Central North Sea) which is based heavily on Deegan & Scull (1977). However, they introduce a so-called "Eocene" shale unit above the Balder Formation (i.e. the basal part of the Hordaland Group.

Knox (in Vinken, 1988) also describes the lithostratigraphy of Quadrant 49 (Southern North Sea) which again relies heavily on Deegan & Scull (1977) replacing the "Undifferentiated" classification for the whole Tertiary as originally described by Rhys (1974). A so-called "Lower Eocene" unit is introduced (presumably equivalent to the "Eocene" unit above) above the Balder Formation (i.e. the basal part of the Hordaland Group).

Nielsen (in Vinken, 1988) applies the same scheme to the Central North Sea area. A composite Late Cretaceous - Early Tertiary offshore section is described below.

The Late Cretaceous "Chalk Group" is a very thick carbonate sequence ranging from Late Albian?/Cenomanian to Danian in age. In the Northern North Sea clastic facies the equivalent unit is the "Shetland Group". With reference to this work, only the Maastrichtian and Danian stages are applicable and will be discussed here.

The Latest Campanian - Maastrichtian is represented by the Limestones of the Tor Formation which is generally "cleaner" than the overlying Ekofisk Formation and is developed as a more "typical" homogenous chalk with chert bands. It reaches a maximum thickness of 473.5 metres in the type well (Shell 1/3-1).

The Danian stage in the offshore North Sea is represented by the Ekofisk Formation: a white, tan or beige, hard, dense limestone with thin chert bands. It is composed mainly of clay sized particles of foraminifera and coccoliths and becomes more argillaceous towards the north though still retaining its high calcareous content. It reaches a maximum thickness of 127 metres in the type well (Phillips 2/4-5). Because of its inclusion within the Chalk Group on obvious lithological similarities, the Danian is often, by association, referred to as "Cretaceous" in North Sea oil "jargon". The important "top Chalk" seismic horizon (i.e. the top Danian where the Ekofisk Formation is present) is, for example, often referred to as "top Cretaceous".

In North Sea "oil jargon" nomenclature, "Tertiary" refers to all post-Danian (some 3000+ metres thick) clastic sediments up to the present day. Sedimentation styles were more varied than in the Cretaceous Chalk Group and economic interest in this interval in the Central and Northern North Sea has resulted in a detailed lithostratigraphic scheme. Essentially, the Palaeocene (Late Palaeocene as used herein) is divided into 2 units, a lower sedimentary fan sequence (the Montrose Group) and an upper, more argillaceous sequence (the Rogaland Group (= Moray Group in the Moray Firth Basin)). A brief description of the Formations within these Groups are given below in Table 6.2.

Maximum thicknesses of Palaeocene sedimentation accumulated in the outer Moray Firth Basin to the north of the most northerly well studied herein (21/26-1D). Thicknesses here are almost double those found in the Central Graben (Parker, 1975; Knox *et al.*, 1981).

GROUP		FORMATION
MONTROSE GROUP Sandstone with variable amounts of argillaceous interbeds and reworked limestones and marls		**MAUREEN FORMATION** Mixed lithologies with irregular distributions. Frequently conglomeratic and contains reworked pebbles. The matrix is brown and dark grey shales silts & sandstones. The "Unnamed Marl Unit" is present over highs and away from sand sources.
Max Thickness: 668m (in 10/1-1A)		Max Thickness: 101m (in 16/1-1)
Age: Palaeocene		Age: Palaeocene
		ANDREW FORMATION Sandstone with claystone interbeds. Sands are fine-medium occasionally coarse, clear-orange quartz. The clays are grey-brown to grey-green and tuffaceous towards the top in the type well. This formation is essentially restricted to the northwest of the region.
		Max Thickness: 302m (in 14/25-1)
		Age: Palaeocene
		FORTIES AND LISTA FORMATIONS Forties is a mainly sandy unit (especially in its upper part) with siltstones and claystones and is found as a large-scale wedge in the Forties area. The Lista is its lateral equivalent and is mainly a non-laminated shale and is found mainly in eastern parts of the North Sea Basin.
		Max Thickness: (F) 239m (in 21/10-1) (L) 151m (in 33/9-1)
		Age: Late Palaeocene
ROGALAND GROUP Argillaceous marine shales with minor sandstone interbeds. Shales become increasingly tuffaceous near the top.		**SELE FORMATION** Tuffaceous montmorillonite rich shales and siltstones with minor interbeds of glauconitic sandstone. This formation is very widespread but maybe absent in the extreme east of the region.
Max Thickness: 196.5m (in 33/9-1)		Max Thickness: 43m (in 16/1-1)
Age: Palaeocene - Early Eocene		Age: Palaeocene - Early Eocene
		BALDER FORMATION Laminated varicoloured fissile shales with interbedded sandy tuffs and occasional limestone stringers and sands. This formation is widespread in the region.
		Max Thickness: 75m (in 25/11-1)
		Age: Palaeocene - Early Eocene

TABLE 6.2: North Sea Palaeocene lithostratigraphic terminology
(after Deegan & Scull, 1977)

The lithostratigraphic scheme of Deegan & Scull (1977) can also be applied, with local modification, to other areas of the North Sea. In the Viking Graben, Knox *et al.* (in Vinken, 1988) have erected the scheme shown in Table 6.3 and from the Outer Moray Firth Basin, Knox *et al.* (in Vinken, 1988) give the scheme shown in Table 6.4.

FORMATION	LITHOLOGIES	AGE	REGIONAL CORRELATIONS
"EOCENE" UNIT	Clays (red at base) below sands	Eocene	none given
FRIGG	Loose sands	Eocene	none given
BALDER	Shales with abundant ash layers in lower part	L.Palaeocene? - E. Eocene	none given
SELE & Equivs.	Shales with rare ash layers passing west into thick sands	L.Palaeocene	none given
HEIMDAL/LISTA	Heimdal: sands & muds with tuffs passing into muds of the Lista	Palaeocene	part of Montrose Group of Deegan & Scull (1977)
EKOFISK	Sands overlain by chalk & marl. Chalks dominate to the south, marls in the north	E.Palaeocene	none given

TABLE 6.3: Lithostratigraphic Terminology for the Viking Graben, North Sea (after Knox *et al.*, in Vinken, 1988) Thick lines are hiati.

FORMATION	LITHOLOGIES	AGE	REGIONAL CORRELATIONS
"EOCENE" UNIT	Green clay below muds & sands	Eocene	none given
BALDER	Tuffaceous siltstones	L.Palaeocene? - E. Eocene	top unit of Moray Group
MORAY GROUP (Beauly Form.)	Sands, muds & lignites	L.Palaeocene	Unit E of Knox *et al.* (1981)
MORAY GROUP (Dornoch Form.)	shales coarsening upwards to sands	L.Palaeocene	Unit E of Knox *et al.* (1981)
UNNAMED	Tuffaceous sands & silts capped by greenish clay	L.Palaeocene	Units C_2 & C_3 of Knox *et al.* (1981)
ANDREW	Massive sands with thin muds with reworking at top & base	Middle? Palaeocene	Units B & C_1 of Knox *et al.* (1981)
EKOFISK	Chalk in between 2 marl units	E.Palaeocene	none given

TABLE 6.4: Lithostratigraphic Terminology for the Outer Moray Firth Basin, North Sea (after Knox *et al.*, in Vinken, 1988) Thick lines are hiati.

The remainder of the North Sea Tertiary is comprised of the Hordaland and Nordland Groups (with a basal "Lower Eocene" unit as described above) ranging from Early Eocene times to the present day.

However, in 1992 a major review work on North Sea lithostratigraphic nomenclature was published in conjunction with the UK Offshore Operators Association (UKOOA). This, at least for the Palaeogene section (Knox & Holloway, 1992), referred to the Central and Northern parts of the North Sea, excluding the Southern area. It also included reference to

Norwegian areas (e.g. Isaksen & Tonstad, 1989) and, more importantly, a revision of lower Palaeogene lithostratigraphy of the Outer Moray Firth by Mudge & Copestake (1992). Both of these works, for the first time, attempted to integrate North Sea biostratigraphic data with lithostratigraphic and sequence stratigraphic data (e.g. Stewart, 1978). Major revisions supplementing previous works and applicable to this study include:

- Abandonment of the Rogaland Group (Mudge & Copestake, 1992)
- Redefining the Moray and Montrose Groups (")
- Redefining the Balder, Sele, Dornoch, Beauly[3] and Lista Formations (")
- Relegation of the Forties Formation to Member status within the Sele Formation (")
- Relegation of the Andrew Formation to Member status within the Lista Formation (")
- Creation of the Cromarty Member within the Sele Formation (")
- Creation of the Balmoral and Glamis Members within the Lista Formation (")
- Replacing the Hordaland Group with the Westray and Stronsay Groups (Knox & Holloway, 1992)
- Creation of the Horda and Mousa Formations within the Stronsay Group (")
- Creation of the Grid, Mey, Tay and various Dornoch Sandstone Members (")

A summary of these new revisions is shown in Text Figure 11 and this nomenclature is adopted herein (see Text Figure 17and Text Figure 19).

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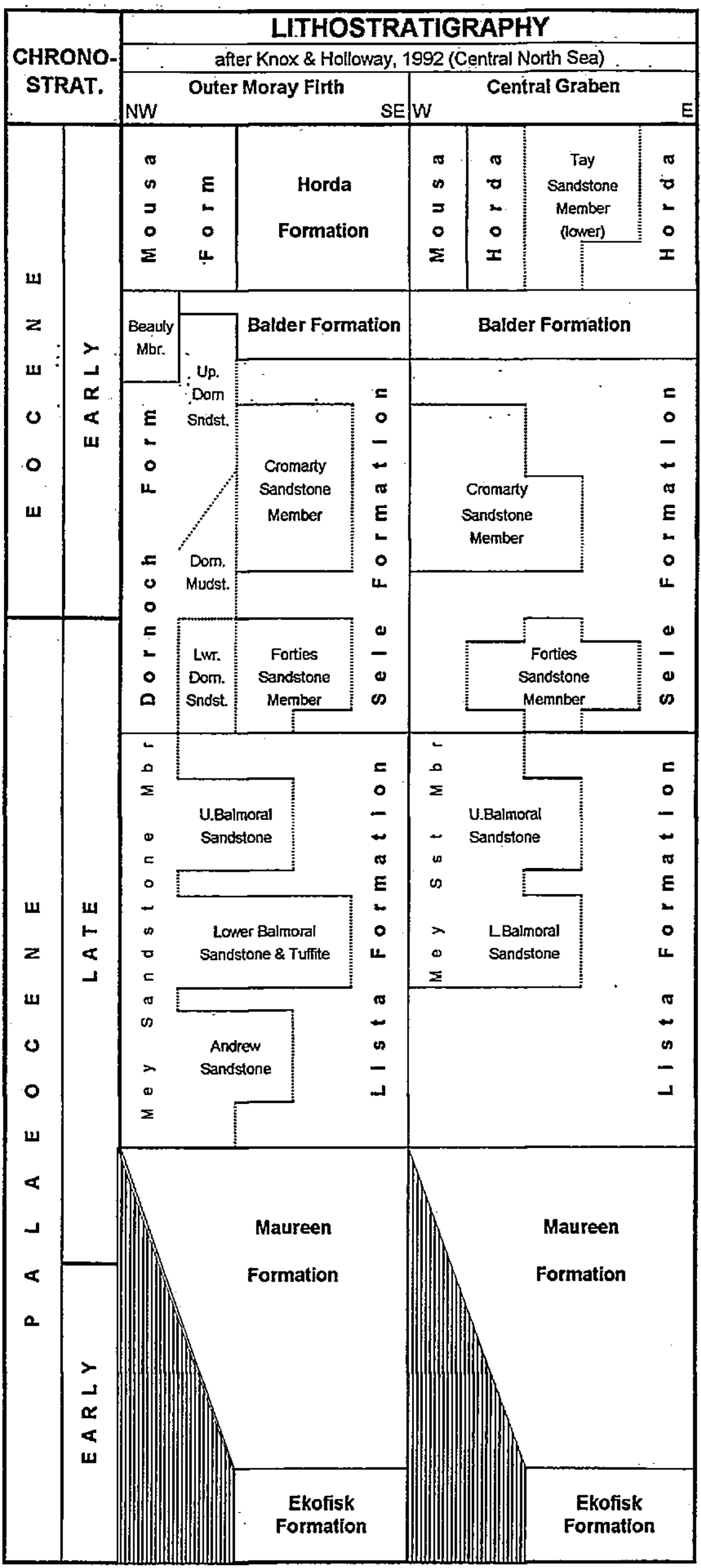
[3] Relegated to Member status in Knox & Holloway, 1992

Text Figure 11: Lithostratigraphy of the North Sea Palaeogene (after Knox Holloway, 1992)



Note: Dashed vertical boudaries illustrate the lateral intergradations between units

In countries immediately surrounding the North Sea Basin, lithostratigraphic nomenclature is highly variable, reflecting in turn the highly variable nature of Palaeocene sediment types in the region.

The onshore U.K. succession has been outlined in previous chapters, particularly Chapter 2. The works of Hester (1965) and Ellison (1983) give good accounts of U.K. Palaeocene lithostratigraphy and a summary can be found in Knox *et al.* (in Vinken, 1988) and this is also summarised below in Table 6.5.

FORMATION	LITHOLOGIES	AGE	REGIONAL CORRELATIONS
LONDON CLAY (A2-E)	Silty clays, interbedded with sand in upper part	E.Eocene	Ieper Clay (Belgium), B-E units = Rosnaes Clay (Denmark), Lower Eocene 3 (Germany)
LONDON CLAY (A1 - Harwich Mbr.)	Glauconitic sands with ash layers	?latest Palaeocene	Olst Formation (Denmark), Lower Eocene 1 tuffites (Ger.)
OLDHAVEN BEDS	Laminated sands	?latest Palaeocene	?=Harwich member of E.Anglia (U.K.)
WOOLWICH & READING BEDS	Woolwich- glauconitic sands, grey shales & shell beds Reading- sands, red muds and sands & pedogenic beds	L.Palaeocene	none given
THANET BEDS	Marine high energy sands to clays in north E.Anglia	L.Palaeocene	none given

TABLE 6.5: Palaeocene Lithostratigraphy of the U.K. onshore (after Knox *et al.* in Vinken, 1988) Thick lines are hiati.

The Danish Palaeocene is divided into the characteristic two-fold lithotypes of Lower Palaeocene carbonates and Upper Palaeocene clastics. The Danian Limestone Formation (of Buchardt-Larsen & Heilmann-Clausen (in Vinken, 1988) had previously been subdivided six-fold by Hansen (1979). The basal unit is a thin dark grey clay/marl "Fish Clay" which overlies Maastrichtian chalks and is succeeded by five limestone members (oldest - youngest:) Cerithium Limestone, Bryozoa Limestone, Coral & Bryozoa Limestone, Saltholm Limestone and, finally, Crania Limestone, all of which (including the Fish Clay) make up the Danskekalk Formation of Hansen (1979). This is overlain by Upper Palaeocene clastics of the Lellinge Greensand and in turn by the Kerteminde Marl. The Lellinge Greensand is mainly developed around eastern Zealand and in the northwest of the Danish sub-basin and, where absent, the Kerteminde Marl lies directly on the Danian Limestone Formation. The boundary is thought to be unconformable and the junction is said (by Buchardt-Larsen & Heilmann-Clausen (in Vinken, 1988)) to represent a "Middle

Palaeocene" regressive event. Above the Kerteminde Marl, the lithostratigraphic terminologies of Hansen and Buchardt-Larsen & Heilmann-Clausen begin to diverge. Hansen has the "Ash Series" of latest Palaeocene - earliest Eocene age which comprises the Grey Unfossiliferous Clay overlain by the Mo Clay/Tuff Clay. These latter units are equivalent to the North Sea Balder Formation. On the other hand, Buchardt-Larsen & Heilmann-Clausen (in Vinken, 1988) have a more detailed lithostratigraphy which, together with their suggested correlations, are shown in Table 6.6 below.

FORMATION	LITHOLOGIES	AGE	REGIONAL CORRELATIONS
Rosnaes Clay	Red, green and grey calcareous clay with several ash layers	E.Eocene	Ieper Clay (Belgium), London Clay above Harwich Member (U.K.), Lower Eocene 2 & 3 (Germany)
Fur	Diatomite with numerous ash layers	L.Palaeocene	Upper Olst (Denmark), Upper Sele - Balder (N.Sea), Dongen Tuff. (Netherlands), Lower Eocene 1 (Germany)
Olst	Mainly clays with ash layers increasing upwards	L.Palaeocene (post Selandian)	Fur (Denmark), Sele - Balder (N.Sea), Dongen Tuffs (Netherlands), London Clay Harwich member (U.K.), Lower Eocene 1 (Germany)
Unnamed	Grey silty clay	L.Palaeocene (U.Selandian)	Erquelinnes Sand (Belgium), Sables de Bracheux (France)
Holmehus	Greenish & reddish clay	L.Palaeocene (U.Selandian)	Thanet (U.K.), Landen (Belgium)
Unnamed	Grey slightly calcareous clay	L.Palaeocene (M.& U.Selandian)	none given
Kerteminde (marl)	Light grey silty marl	L.Palaeocene (E.& M.Selandian)	none given
Lellinge (greensand)	Glauconitic sandy marly and grey clay with basal conglomerate	L.Palaeocene (E.Selandian)	none given
Danian limestone	Limestones & chalk	E.Palaeocene	none given

TABLE 6.6: Danish Palaeocene Lithostratigraphy (after Buchardt-Larsen & Heilmann-Clausen in Vinken, 1988) Thick lines are hiati.

The Dutch Palaeocene is superficially similar comprising of Lower Palaeocene limestones and Upper Palaeocene clastics overlain by ash-bearing formations. Much of the recent (on and offshore) lithostratigraphic subdivisions have been refined by the Rijks Geologische Dienst (RGD) organisation and the Nederlandse Aardolie Maatschappij (NAM) Oil Company (1980) and summarised by RGD in Vinken (1988) and in Table 6.7.

FORMATION	LITHOLOGY	AGE	REGIONAL CORRELATIONS
DONGEN (Ieper Clay Mbr.)	Greenish, grey & brown glauconitic clays	E.Eocene	London Clay (B-D) (U.K.), Lower Eocene 2-4 (Germany)
DONGEN (Basal Dongen Tuffite Mbr.)	Grey & brown clays with tuffs	E.Eocene	Upper Basal Dongen sand mbr. (Neth.), Balder (N.Sea), Olst (Denmark), Lower Eocene 1 (Germany)
DONGEN (Basal Dongen Sand Mbr.)	Glauconitic sands with minor clays	lst.Palaeocene - est.Eocene	Lower Basal Dongen tuffite mbr. (Neth.)
LANDEN (Landen Clay Mbr.)	Calcareous grey clays & marls	L.Palaeocene	none given
LANDEN (Heers Sand Mbr.)	Calcareous glauconitic sands	L.Palaeocene	none given
HOUTHEM	Grey & yellow chalky limestones	E.Palaeocene	none given

TABLE 6.7: Palaeocene Lithostratigraphy of the Netherlands
(after RGD in Vinken, 1988) Thick lines are hiati.

The Belgian Palaeocene is somewhat more complicated, being subdivided several-fold probably as a function of the more marginal marine - terrestrial nature of the environments of deposition which, in turn, seems to have led to many more different facies types. Moorkens (1982) and Hooyberghs (1983) have the Mons Formation overlying the Tuffaceous Chalks of Maastricht (Maastrichtian). The Mons Formation is comprised, from the base up, of the Malagne Conglomerate, Tuffeau de Ciply, Calcaire de Cuesmes, Calcaire de Mons and finally, lacustrine and/or continental deposits. Each of these units are separated by a hiatus. The Mons Formation is shown as being Danian in age but also extending into the lower part of what in this project is termed Thanetian (Late Palaeocene). It is unconformably overlain by the Heers Formation which comprises the Gelinden Marls, which is subsequently conformably overlain by the Landen Formation which comprises the Tuffeau de Lincent and the sands or lignites of Landen. The succession continues (unconformably) with the Ypre Formation, Ypres Clay unit. However, Laga (in Vinken, 1988) reviews the lithostratigraphy somewhat differently (see Table 6.8).

FORMATION	LITHOLOGY	AGE	REGIONAL CORRELATIONS
IEPER (Ledeberg, Vorst or Egem sand members)	Glauconitic sands, grey-yellow clays & clayey sands	E.Eocene	none given
IEPER (Vlaanderen clay member)	Grey-blue clay	E.Eocene	London Clay (U.K.), Rosnaes Clay (Denmark), Lower Eocene 3 (Germany)
LANDEN ("upper non-marine part" - depending on location)	Clays & lignite	L.Palaeocene	
Erquelimes sand mbr.	Marine sands		Woolwich Bottom Beds (U.K.)
Grandglise sands			
Oostende-ter-Streep	Lignitic clays & sands with shell bands		
Orsmaal-Dormaal sand (formerly the lignites & sands of Landen)	Sands with lignitic clays and marls with a gravel base		
Loksbergen complex	Lignites, clays, marls & sandy clays		
LANDEN ("lower marine part" - depending on location)		L.Palaeocene	The lower marine Landen correlates with the Landen Clay Mbr. (Neth.) and the Thanet Formation (U.K.)
Hoegaarden-Racour sands	Glauconitic sands		
Tuffeau d'Angre	Clayey glauconitic sands		
Louvil clay	Thin clay		
Waterschei	Hard clay		
Lincent Tuffeau mbr.	Siliceous limestones, marls with a basal glauconitic flinty sand		
HEERS (Gelinden Marl)	Marl with glauconitic base	L.Palaeocene	lower part of the Landen Formation (Neth.)
HEERS (Orp Sand)	Glauconitic clayey sands	L.Palaeocene	ditto
HAININ MEMBER	Freshwater limestones	E.- ?M. Palaeocene	lower Landen (Neth.), non-marine beds (Germany)
MAASMECHELEN	Grey sandy calcarenite	E.- ?M.Pal.	none given
MAASMECHELEN (Bunde Limestone)	Limestone?	E.- ?M. Palaeocene	none given
MAASMECHELEN (Vroenhoven Mbr.)	White-yellow calcarenite with glauconitic base	E.- ?M. Palaeocene	none given
MONS (Mons Limestone Mbr.)	Yellowish calcarenite	E.Palaeocene (Dan & Mon)	none given
MONS (Ghlin & Ciply Mbr.)	ditto	ditto	none given
MONS (Poudingue de la Malogne)	Conglomerate	ditto	none given

TABLE 6.8: Palaeocene Lithostratigraphy of Belgium (after Laga in Vinken, 1988) Thick lines are hiati.

The German Palaeocene is also relatively complex with many regional variations and four main areas are recognised: The Lower Rhine Embayment, Lower Saxony, the Schleswig-Holstein area and what used to be the German Democratic Republic. For the purposes of this summary only the terminology for Lower Saxony will be summarised here (see Table 6.9: after von Daniels & Gramann in Vinken, 1988) as this region borders the North Sea area.

FORMATION	LITHOLOGY	AGE	REGIONAL CORRELATIONS
LOWER EOCENE	Marly multicoloured clay.	E.Eocene	Upper London Clay (U.K.)
LOWER EOCENE 2	Clay	E.Eocene	none given
LOWER EOCENE 1	Clays with ash layers	est. Eocene	Balder (N.Sea), Olst (Denmark)
"UPPER PALAEOCENE"	Calcareous & non calcareous clays with basal conglomerate & glauconite	L.Palaeocene	none given
PENNINGSEHL	Marine clays	L.Palaeocene	Kerteminde Marl (Denmark)
GODRINGEN	Calcarenitic sands & conglomerates	M.Palaeocene	"Montian" (Belgium), ?Sohlingen (below)
SOHLINGEN	Marine clays & sands / non-marine clays & coals	M.Palaeocene	"Montian" (Belgium), ?Godringen (above)
DANIAN LIMESTONE	Limestones & shales	E.Palaeocene ("M.Danian")	none given

TABLE 6.9: Palaeocene Lithostratigraphy of NW Germany (after von Daniels & Gramann in Vinken, 1988) Thick lines are hiati.

A synthesis of the various lithostratigraphic schemes for the northwest European countries and the offshore schemes is shown in Text Figure 12.

6.4.Wireline-Log Correlation

The samples from the various North Sea boreholes used in this study were supplied along with certain wireline log traces for the interval sampled. In most cases, these consisted of the Gamma and Sonic logs. Most North Sea Palaeocene formations give characteristic "signature" responses for these types of log which are described below. Note these are "ideal" cases and are not necessarily present in every well studied.

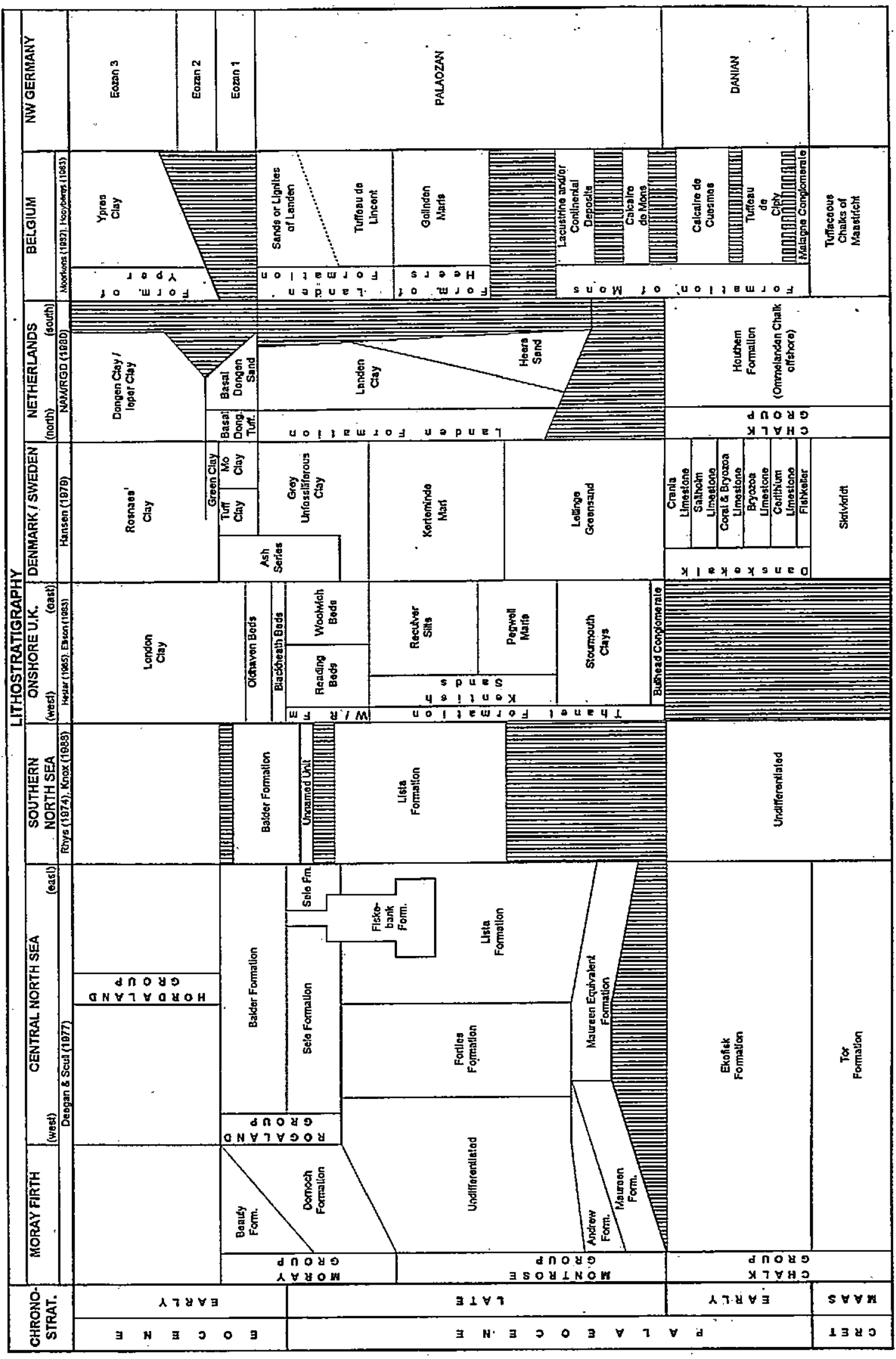
One of the most consistent and reliable wireline log motifs in the Early Tertiary is the characteristic wireline log signature for the Balder Formation. The concentration of tuffaceous lithologies in this formation, causes the gamma log tool to read low API values. The top of the Balder Formation however, is normally manifested by a prominent gamma "spike" which occurs stratigraphically near the bottom of the Lower Eocene. This spike is therefore taken to mark the top of the Balder Formation and, because of the process of deposition (atmospheric ash fall-out) can be assumed to be isochronous throughout the North Sea area. The bulk of the Balder Formation (i.e. below the gamma spike) displays typically, a "bulging" gamma pattern with minimum API values at the approximate mid point of the formation, i.e. an approximate "C" shape. This spike and bow motif is particularly well displayed in well 29/25-1. The highest stratigraphical occurrence (extinction) of the diatom *Coscinodiscus* sp.*1*, which is a characteristic fossil component of the Balder Formation (see Chapter 2.3.2) normally occurs some way below the gamma spike throughout most of the North Sea (see the palaeontological distribution charts for, particularly, the 29/25-1 well).

However, a potential problem is that the southerly extent of the ash-falls formed by Hebridean vulcanism, which characterises the Balder Formation so well, is not accurately known (see also Chapter 2). The gamma spike defining the top of this formation may be absent or much less pronounced. This is particularly true of the wireline trace in well 44/2-1 where the spike is absent or very small and the "bowing" effect is slight. The wireline trace in well 49/20-2, further south again, is even less forthcoming with no obvious gamma breaks displayed at the appropriate stratigraphic level. However, somewhat unexpectedly, a fairly good Balder signature can be seen for well 49/24-2. Clearly, the southern limit of ash development seems to be highly variable geographically and probably temporally aswell.

Gamma ray values normally show an increase within the underlying Sele Formation and are largely variable and less formation-specific throughout the remainder of the Palaeocene succession, becoming relatively higher again within the Maureen Formation, particularly where marly.

An abrupt shift to very low gamma API values is nearly always observed at the junction with the Chalk Group (of which the Early Palaeocene (Danian) Ekofisk Formation is the uppermost unit). This is particularly noticeable in the Central and Southern North Sea areas where relatively pure Danian (to Upper Cretaceous) limestones occur. The equivalent units in the north (Shetland Group) are more clastic in nature and sometimes the log-change is difficult to observe. The wireline log trace of well 21/26-1D displays this feature particularly well. However, it must be remembered that this junction is often developed as a hiatus/unconformity/erosion surface in the North Sea area with the Danian Ekofisk Formation often missing. It is only by using biostratigraphy that the presence and extent of this hiatus can be determined. This is well illustrated by the wells 21/26-1D and 29/25-1: both wireline (gamma) traces display very similar motifs which mark to top of limestones attributed to the Chalk Group. However, biostratigraphy clearly shows that the ages of the uppermost units of the Chalk Group are markedly different (see Chapter 9).

Text Figure 12 Selection of NW European Lithostratigraphical Schemes



6.5.Sequence Stratigraphy

With the major Tertiary (specifically Early Palaeogene) hydrocarbon accumulations in Northwest Europe being concentrated in and around the Central North Sea, it is not surprising that intensive studies have been undertaken in all aspects of geoscience, in and around this region. In recent years, a geoscientific "tool" has evolved whose approach integrates several individual geoscience facets which can lead to better understanding of the evolution of sedimentary basins.

Sequence Stratigraphy (a.k.a. Seismic Sequence Stratigraphy) attempts to clarify the process by which a sedimentary basin evolves at almost any level of scale from individual bed up to the entire basin itself. The fundamental unit of the approach is known as the "depositional sequence" and the stratigraphic record can thus be defined by the disposition of sequences and the facies variation(s) within them.

A comprehensive discussion on the principles of Sequence Stratigraphy is beyond the scope of this thesis and the reader is referred to Galloway (1989) and Wilgus *et al.* (1988) for further information. However, a very brief summary is given here. To optimise stratigraphic prediction (in an exploration sense) three basic correlation tools are used:

- lithostratigraphy
- biostratigraphy
- seismic stratigraphy

It should be stressed that *no one tool alone is adequate to make definitive correlations.* The principles of lithostratigraphy and biostratigraphy are discussed elsewhere in this thesis, although they can be summarised thus:

Lithostratigraphy is the organisation of rock strata based on their lithological character. The concept of "time" plays no part in the establishment of lithostratigraphic units.

Biostratigraphy is the organisation of rock strata based on their fossil content. Biostratigraphic boundaries *may* locally coincide with lithostratigraphic boundaries but, as a rule, they lie at different stratigraphic horizons. Biostratigraphic correlation may *approach* true time correlation (Chronostratigraphy), particularly in more distal basin environments, but is never fully equivalent to it. Depositional environment can strongly influence faunal distribution and biostratigraphic boundaries may diverge from a time-line within an individual basin.

However, Sequence Stratigraphy is fundamentally related to chronostratigraphy.

The idea of Seismic Stratigraphy was originally developed by geoscientists from the EXXON organisation and published by Vail *et al.* (1977) and has been applied in many geological situations, especially hydrocarbon exploration. The concept being that primary seismic reflections are generated by stratal surfaces which are thought to be chronostratigraphic in nature and thus do not transgress geological time. Following on from this hypothesis, it was realised that unconformities, as well as stratal surfaces, also have chronostratigraphic significance. These basin-wide isochronous surfaces separated packages of sediments with characteristic seismic signatures which were termed "seismic sequences". This work focussed attention on cycles of sea-level changes within which "sequences" were deposited. Later, the pattern of "off-" and "onlap" sequences enabled the derivation of a curve showing the relative changes in sea-level that caused such patterns through the Tertiary (Vail & Hardenbol, 1979). This was, in turn, expanded upon by Vail *et al.* (1984) and Haq *et al.* (1988) to a global eustatic curve throughout the Tertiary and much of the Meso- and Palaeozoic (see below).

It is these primary seismic reflections which define the individual Depositional Sequences within the Sequence Stratigraphic concept. Seismically correlatable sequence boundaries (as can be obtained from a standard seismic section) can be tied together using lithostratigraphic and biostratigraphic information. The "Vail" model has been expanded upon by Van Wagoner and others (e.g. 1988, 1990) and Haq and others (1988), also of the Exxon Group. However, in simplistic terms, the main upper and lower sequence boundaries tended to coincide with periods of maximum sea-level fall. Subsequent sea-level rise occurred which eventually reached a maximum landward extent at some point *within* the sequence before retreating again to the next sea-level minimum. Each sequence was essentially bounded by a recognisable, isochronous seismic surface which was unconformable (or if conformable, at least correlatable) across most of its areal extent. Formally defined:

> *"Sequence stratigraphy is the study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or nondeposition, or their correlative conformities"* (Van Wagoner *et al.*, 1988)

Another method of defining depositional sequences (the so-called "genetic" sequence stratigraphy) has been proposed by Galloway (1989) which, in basic terms, recognises the same structural components of the depositional sequence model *sensu* Van Wagoner *et al.*, 1988 although places the emphasis on major sequence boundaries at successive Maximum Flooding Surfaces (see below) - in effect a 180° shift from the "Van Wagoner" model. Galloway regards a sequence as:

> *"...a package of sediments recording a significant episode of basin margin outbuilding and basin filling bounded by periods of widespread basin-margin flooding"* (Galloway, 1989)

Galloway believes that the maximum flooding surface represents a time of major palaeogeographical change and the reorganisation of basin-floor geometries. In the following discussion the terms "*sensu* Van Wagoner" and "*sensu* Galloway" will be used to distinguish the two models.

An addition to the seismic stratigraphic concept is the appreciation that stratigraphic cyclicity develops as a response to the interplay between sedimentation rates and subsidence rates during the evolution of a basin:

Sedimentation Rate	Subsidence Rate	Sedimentation Pattern	Direction of Shoreline Movement
HIGH	LOW	REGRESSIVE	BASINWARD
EQUAL	EQUAL	STILLSTAND	NONE
LOW	HIGH	TRANSGRESSIVE	LANDWARD

TABLE 6.10: Results of the interplay between varying rates of sedimentation rate and subsidence rate in a deltaic environment (after Weimer, 1975)

This stratigraphic cyclicity is known as "Facies Cycle Wedges" (White, 1980) and that, ideally, a "wedge" comprises a basal non-marine facies overlain by coarse-grained facies. The mid-wedge is dominantly a fine-grained, transgressive facies which is separated from an overlying coarse facies progradation by a mid-wedge unconformity. The top-wedge is characteristically a regressive coarse-grained facies passing up into a non-marine final facies.

Each wedge contains three Sequence Boundaries which, from base upwards are - the initial transgressive surface, the maximum flooding surface and the maximum regression surface:

1)**The Initial Transgressive Surface:**

(Sequence Boundary *sensu* Van Wagoner)

The first significant marine flooding surface across the previous shelf. A series of successive (pulsatory) transgressions eventually develops a certain thickness of strata composed of a series of retrogradational subsequences, with a minor transgression at the base of each subsequence. The number of such subsequences may vary across the shelf.

2)**The Maximum Flooding Surface:**

("Genetic" Sequence Boundary *sensu* Galloway)

The maximum landward extent of the successive transgressions above. It generally consists of a fine-grained condensed section resulting from a sea level rise outpacing sediment supply. This surface is very close to a true basin-wide synchronous event. The high level of the sea during the time of deposition of a Maximum Flooding Surface introduces the term "highstand system". It is during (and after) the "highstand" that most basinward progradation of clastic sediment occurs with the flooding surface in effect "switching off" the sand supply system from the preceding depositional sequence. This often results in the reorganisation of basin-floor topographies and palaeogeographies which marks a crucial stage for the application of Galloway type sequence models (see above).

3)**The Maximum Progradation[4] Surface:**

This is the time of greatest basinward extent of the shoreline formed in response to large scale clastic progradation initiated during the preceding "highstand". Like the Initial Transgressive Phase in 1) above, the resulting "regression" is pulsatory and forms a series of subsequences within this unit. The shoreline associated with the Maximum Progradation is regionally diachronous and low nett sea levels lead this phase of the cycle to be termed a "lowstand system". It is during the "lowstand" where basin-floor submarine fans are often developed at the foot of the shelf (along with incised valleys on the exposed shelf) and these can be prime exploration targets in clastic depositional systems. To form a Van Wagoner type sequence boundary with the subsequent sequence above, the sea-level fall should preferably be to below the shelf edge, thus resulting in subaerial exposure of much of the shelf at this point.

The three features, which are illustrated in Text Figure 13, can be recognised on most seismic sections, well-log data, outcrop sections and (for two of the above only) fossil records.

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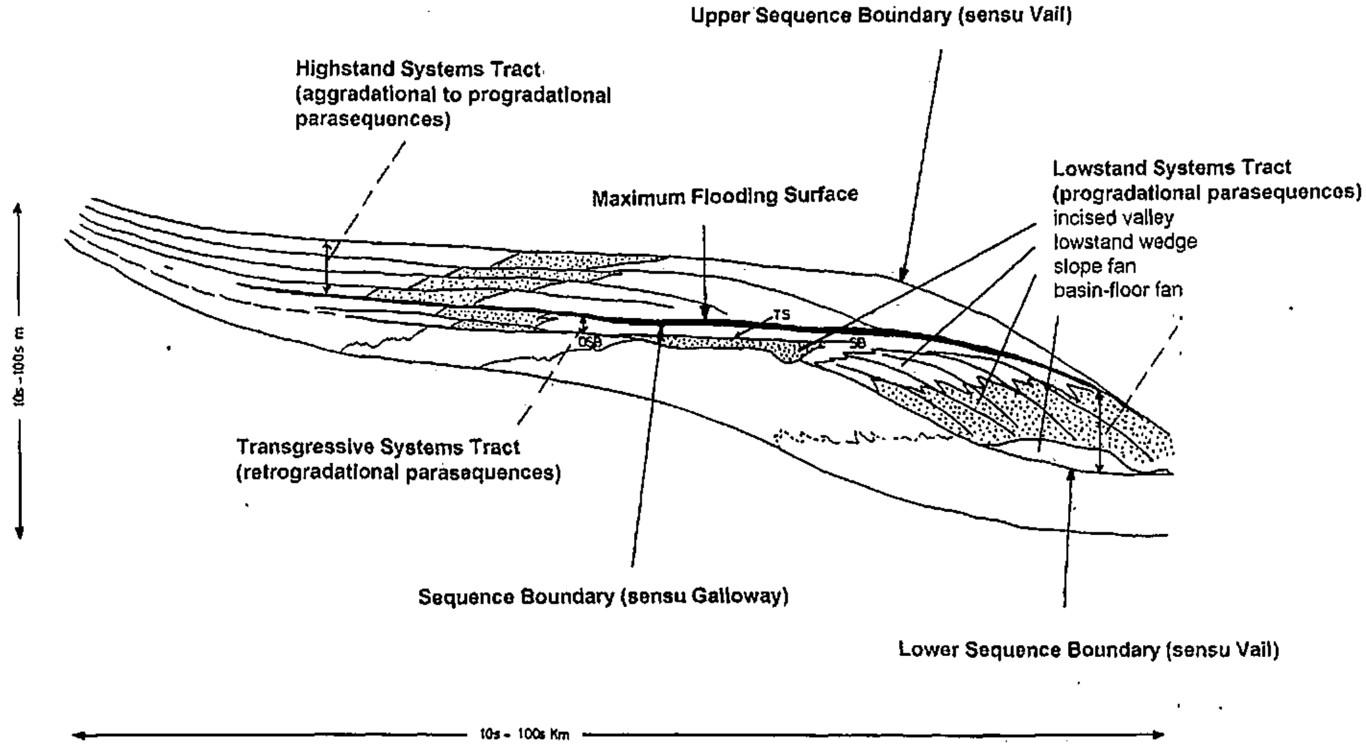
[4] Note that the term Maximum "Regressive" Surface (used in some definitions) is avoided as progradation, especially if sediment input is high may, in effect, "force" a shoreline retreat which may not always be accompanied by eustatic sea-level fall.

Text Figure 13 Simplified diagram of the typical components of a Stratigraphic Sequence



DSB = Depositional Shoreline Break

SB = Shelf Break

TS = Transgressive Surface

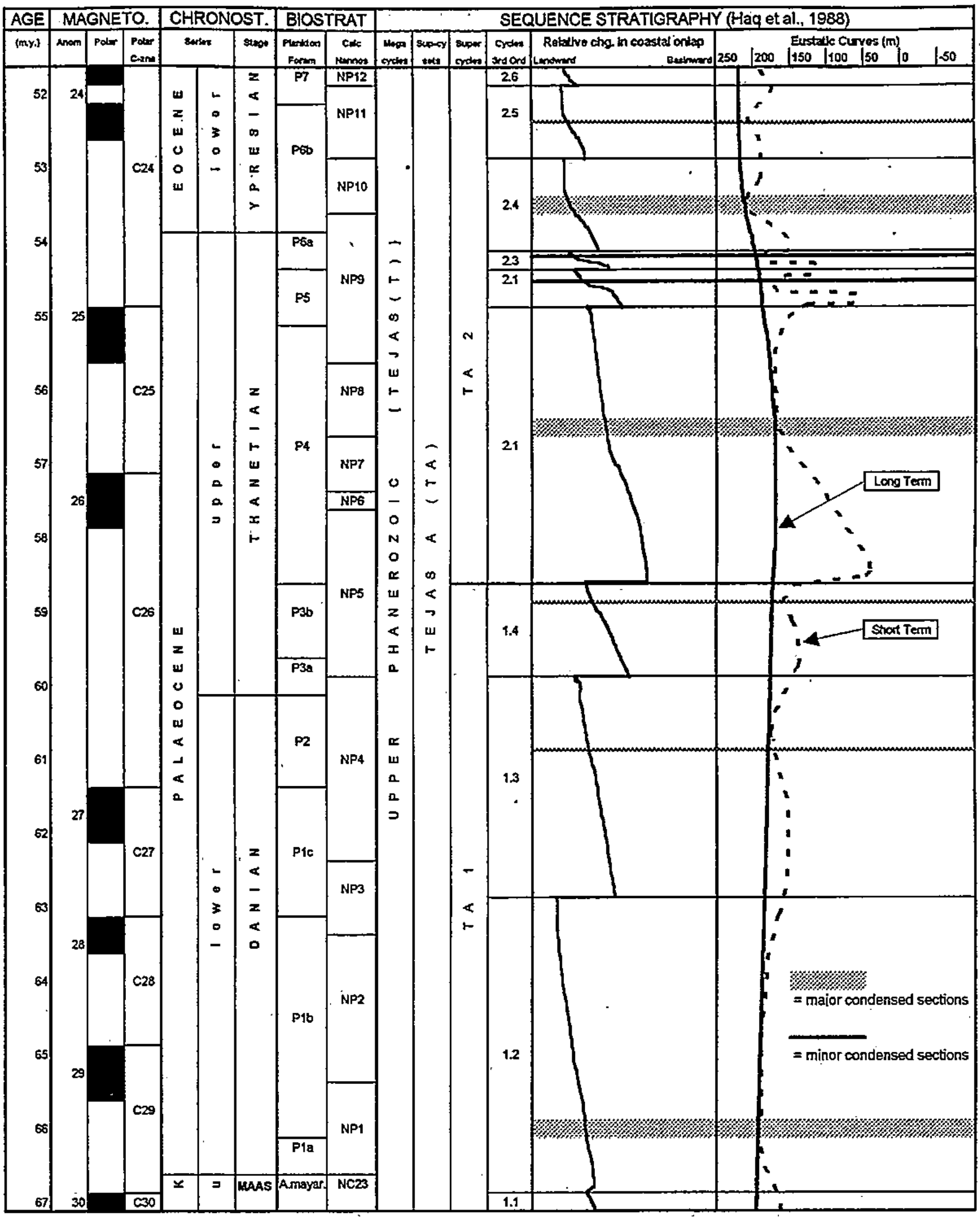
DATA TYPE	INITIAL TRANSGRESSION	MAXIMUM FLOODING SURFACE	MAXIMUM PROGRADATION
Seismic Section	Onlap Surface	Downlap Surface	Erosional Truncation
Well Data	Marine mudrocks	High gamma spikes in clays, hardgrounds, cherts etc.	Difficult to see. ?top of coarsening-up cycles? palaeosols? etc.
Outcrop	Thin pebble/well sorted transgressive lags	Black shales (as above)	Top of coarsening-up cycle (coals), calcrete, palaeosols etc.
Fossil Record	No apparent *in situ* faunas but reworked taxa may be present	Abundant faunal diversity (planktonic & benthonic), apparent missing biozones in deep water environments	Unconformity (missing section) rather than hiatus or condensed section. Non-marine indicators

TABLE 6.11: The recognition of Sequence Boundaries

Using various sequence stratigraphic concepts and a multidisciplinary approach involving magnetostratigraphy, radiometric data, biostratigraphy, seismic stratigraphy etc., Haq *et al.* (1988) produced a series of charts showing magnetochrono-, standard chrono-, biochrono- and sequence chrono-stratigraphical schemes, tied to eustatic sea-level curves and coastal onlap curves, for the entire Mesozoic and Cenozoic.

The curves remain the subject of some controversy with some workers (see for example Hallam's criticisms (Hallam, 1988) for the Jurassic) and a revised curve is due to be published in the near future. However, the "original" curve serves as a useful guide to sea-level patterns for the Palaeocene interval as studied herein. It should be born in mind, however, that the curve is a composite from data taken worldwide and does not take into account local factors such as local tectonism. Local graben-tectonism in the North Sea has been shown to markedly affect sequence deposition in the Jurassic (Partington *et al.*, 1993) and North Atlantic tectonism certainly had similar effects on Palaeogene depositional patterns. The Palaeocene section is summarised in Text Figure 14.

Text Figure 14: Global eustatic sea-level curve for the Palaeocene (after Haq *et al*., 1988)



Haq *et al.*'s curve shows that the Palaeocene essentially represents a period of slow but steady sea-level fall, continuing a trend started from a sea-level maxima during the late Campanian (although not as high as the absolute sea-level maximum achieved during the Turonian). However, on a smaller scale, they have been able to identify several marked shallowing and deepening events which are presumed to be global in distribution and eustatic in origin. Major condensed sections, seen near the base of the Danian, mid Thanetian and earliest Ypresian, are formed during periods of major marine flooding events ("Maximum Flooding Surfaces" of both Van Wagoner and Galloway type sequences).

Of the two sequence stratigraphical "models" (Van Wagoner and Galloway type sequences), the author must express a preference for the use of the Galloway-type sequence model when dealing with North Sea sequence stratigraphy. The Van Wagoner model is undoubtedly valid, but nevertheless has certain limitations when applied to North Sea subsurface geology using present techniques. The concept of the Van Wagoner model originated from studies in, amongst others, the Gulf of Mexico region. This area contains the essential "ingredients" used to construct a classic Van Wagoner type sequence:

- a hinterland (sediment source)
- a sediment distribution system (alluvial, fluvial and deltaic)
- a regular shore and shoreface belt
- a continental shelf
- a shelf edge
- a shelf slope
- a shelf slope base (bathyal/abyssal plain)

However, the North Sea Basin (and particularly the southern North Sea area considered herein) throughout much of geological history, has lacked the final three components - it being essentially an intra-cratonic basin rather than being a true continental shelf / plate margin setting. This can make the recognition of a so-called Type 1 Sequence Boundary (*sensu* Van Wagoner) difficult, as the formation of such a boundary requires a fall in sea-level to at least below the "depositional shoreline break" and, preferably, below the "shelf break".

Also, the sequence-bounding surfaces are defined as "unconformities or their correlative conformities" in the Van Wagoner model and unless biostratigraphical resolution is excellent, these surfaces can be difficult to identify at resolutions below those of the seismic (i.e. third-order cycles or perhaps as little as 0.5 million years duration). Most biostratigraphical work on offshore boreholes relies on samples spaced too widely to accommodate this required resolution.

In addition, the absolute duration of a sequence-bounding unconformity can vary across its area, and approaches zero in the basinward facies where the surface becomes a "correlative conformity". It is thus difficult to constrain the sequence boundary biostratigraphically and, consequently, impossible to state definitive ages for individual sequence boundaries.

Recently, the application of the Van Wagoner model to the Jurassic of the Inner Moray Firth area - one of its key "testing areas" (Vail & Todd, 1981; Vail *et al.*, 1984) has been questioned. Originally, the cause of major Jurassic unconformities in this area was thought to be dominantly eustatic. However, it appears that local or regional extensional tectonics and associated footwall uplift may have played a more significant role in their formation (Underhill, 1991; Partington *et al.*, 1993).

On the other hand, the recognition of Galloway-type sequence boundaries (i.e. flooding surfaces) are potentially easier in subsurface boreholes. They can be apparent on wireline log signatures as gamma-ray "peaks" reflecting the condensing of sediments at flooding surfaces. The junction between two log trends, representing retrogradation and overlying progradation of sediments, often coincides with the gamma maxima as well as a resistivity minima.

Secondly, they can also be recognised by biological signatures, notably the recovery of abundant and diverse planktonic microfossils. These are events that occur significantly below the level of seismic resolution using present hardware technology and data processing techniques.

The Galloway approach (together with substantial biostratigraphical input) has been used with apparent success in the Jurassic of the Moray Forth Basin (Stephen *et al.*, 1993) and from the Jurassic of the Central North Sea (Partington *et al.*, 1993).

With respect to Tertiary sequence stratigraphy, many seismic sequence stratigraphic approaches (i.e. *sensu* Van Wagoner) have been made on a local (field) scale in the North Sea area (McGovney & Radovich, 1985, and Armstrong *et al.*, 1987 for the Frigg and Gannet fields respectively). However, Stewart (1987) applied the concept on a regional scale (Central North Sea) and recognised 10 depositional sequences, each separated by unconformities (i.e. sequences *sensu* Van Wagoner) and calibrated by biostratigraphy to give a composite chronostratigraphy. This scheme is reproduced in Text Figure 15 along with Stewart's coastal onlap curve for the same interval.

Stewart's first depositional sequence - the Danian Chalk, is composed of large-scale allochthonous chalk units which were deposited by slumping, debris flow and turbidity flow processes in a slope setting (Watts *et al.*, 1980). However, this rather over-generalises the

picture as although that statement is true in many parts of the North Sea, it does not exclude the formation of at least part of the Danian limestones by characteristic chalk-depositional mechanisms. The Danian Chalk sequence of Stewart can be thought of as a transitional deposit marking the end of a long period of tectonically quiescent shelf-carbonate deposition during Late Cretaceous times and the beginning of an equally long period of basinal, more tectonically controlled, siliciclastic deposition during the Tertiary.

Overlying the Danian Chalk sequence, Stewart recognises three large-scale fan systems which were deposited within a relatively short time of each other. The first of these, the Maureen Fan complex, was laid down during late Danian times over the Danian Chalk with an associated basal debris flow deposit. This was succeeded by the Andrew Fan and the Forties Fan in early and late Thanetian times respectively (see Text Figure 15). These fans are separated, particularly in more basinal areas by hemipelagic mudstones which Stewart correlates with transgressive episodes. During these times of high sea levels (highstands), the main sediment source into the Central North Sea was from the Scottish Mainland. However, during regressive phases and lowstands which deposited the three main fan complexes, provenance was mainly from the East Shetland Platform.

Stewart indicates 5 major regressive phases and 4 main highstands during Palaeocene and Early Eocene times in the Central North Sea with almost all of them associated with hiatuses. The Depositional Sequence stratigraphic scheme is very detailed with 10 discrete sequences:

Sequence 1

The earliest Palaeogene depositional sequence, the base of which is a widespread seismic marker horizon at the boundary between the Danian and Late Cretaceous chalks (Ekofisk Formations and Tor-Hidra Formations of Deegan & Scull, 1977). The sequence is composed primarily of chalky limestones although basal sands and silts are evident in the South Viking, and Witch Ground Grabens. This sequence contains Danian planktonic foraminifera, probably equivalent to Subzones NSP1a-b of King (1989).

Text Figure 15 **Central North Sea Palaeocene depositional sequences (after Stewart, 1987)**

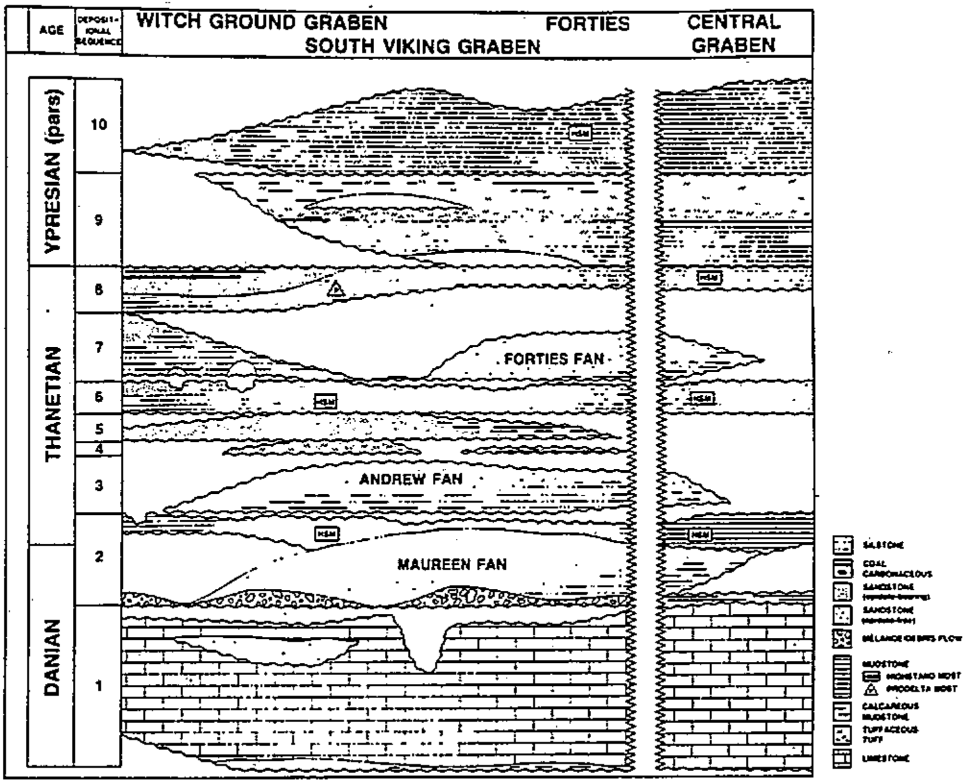


Fig. 10.19. Composite chronostratigraphical diagram for the early Palaeogene of the central North Sea. (From Stewart, 1987, reproduced by permission of Graham and Trotman Limited.)

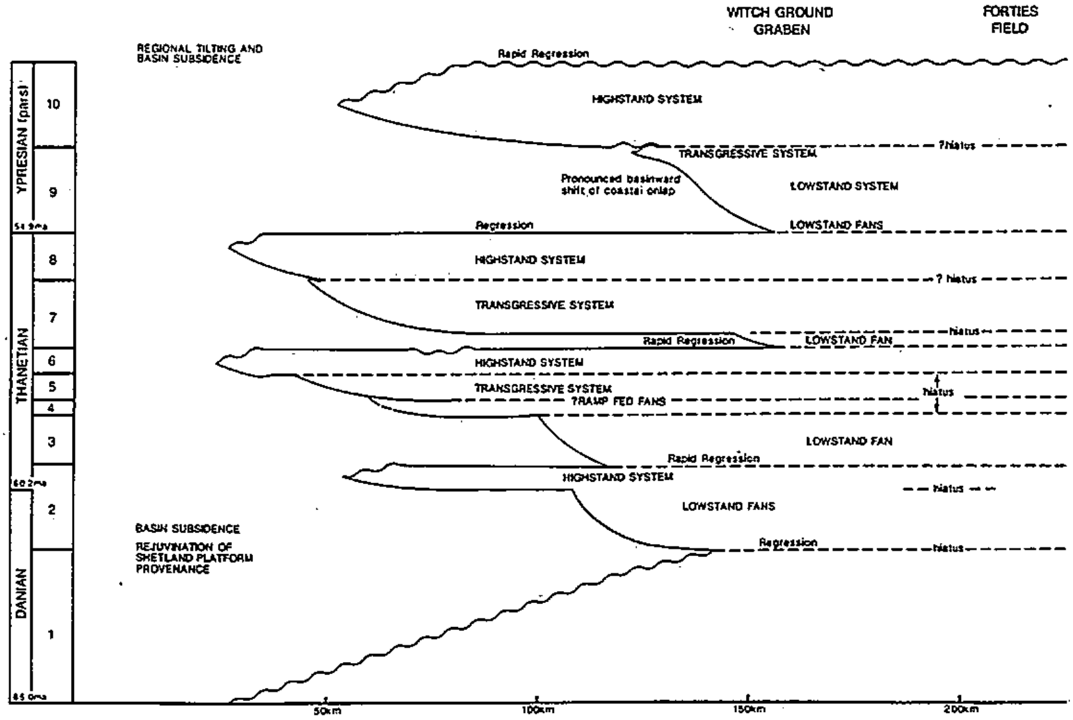


Fig. 10.20. Coastal-onlap curve for the early Palaeogene of central North Sea, showing the relative onlap position of each of 10 depositional systems. The terms highstand and lowstand refer only to the relative position of sea level. (From Stewart, 1987, reproduced by permission of Graham and Trotman Limited.)

Sequence 2

This sequence contains three lithostratigraphic subunits. **Subsequence 2A** consists of debris flow deposits including reworked Cretaceous and early Danian chalks and is dated as late Danian in age. **Subsequence 2B** is a submarine fan sandstone of late Danian - earliest Thanetian age. **Subsequence 2C** is a widespread hemipelagic mudstone of early Thanetian age. This mudstone yields the *Cenodiscus* radiolarian assemblage (Zone NSP2 of King, 1989).

Sequence 2 includes part of the Maureen Formation (Deegan & Scull, 1977). The submarine fan sand (2B) is Stewart's Maureen Fan (see Text Figure 15).

Sequence 3

Sequence 3 consists primarily of submarine fan sandstones of the Andrew Fan, correlatable in part with the Andrew Formation of Deegan & Scull (1977). These sands have an East Shetland Platform provenance as described by Morton (1979) and Knox *et al.* (1981). Sequence 3 lies within the lower part of the range of *Spiroplectammina spectabilis* (Grzybowski) (the *Bolivinopsis spectabilis* biozone of Stewart, 1987) (uppermost part of Zone NSA1 of King, 1989) i.e. early Thanetian.

Sequence 4

Sequence 4 is relatively thin and areally restricted. It comprises tuffaceous sandstones and mudstones. The sands are of Scottish Mainland provenance (Morton, 1979, Knox *et al.*, 1981). The volcanic material in sequence 4 is consistent with the recognition of thin ash layers over widespread areas of the North Sea (Jacqué & Thouvenin, 1975). These ash layers are correlated with pyroclastic phase 1 of Knox & Morton (1983) which can also be traced throughout the Southern North Sea and into the Thanet Beds of SE England (Knox & Harland, 1979).

Sequence 5

Sequence 5 is restricted to the Outer Moray Firth and South Viking Graben areas and comprises submarine fan sands with common internal discontinuity surfaces. These sands have a Scottish Mainland provenance (Morton, 1979 and Knox *et al.*, 1981). The sands continue to yield agglutinating foraminifera of the *B.spectabilis* biozone (King's Zone NSA1) of early Thanetian age and correlates with part of the Undifferentiated Montrose Group of Deegan & Scull (1977).

Sequence 6

Sequence 6 is generally thin but widespread, and comprises green to brown mudstones and siltstones. It is correlatable with the upper part of the Undifferentiated Montrose Group of Deegan & Scull (1977) and equates to the Forties Formation Shale Member of Carmen & Young (1981). The sequence yields diverse agglutinants of Stewart's *B.spectabilis* biozone, which, when taken into conjunction with palynological data, indicates a late Thanetian age for sequence 6. Stewart infers a demise in the diverse *infaunal* agglutinated foraminifera near the top of this sequence but indicates that they are replaced by an impoverished *epifaunal* agglutinated fauna in the uppermost beds of sequence 6. Stewart correlates this change with increasing basin anoxicity and a rise in the aerobic/anaerobic boundary in the sediment/water column.

Sequence 7

Sequence 7 is separated from sequence 6 by a regional discontinuity identified by Rochow (1981) which separates the Montrose and Moray Groups in the Outer Moray Firth. Sequence 7 includes the Forties reservoir, which is a submarine fan sandstone, and slope mudstones. The sands have an East Shetland Platform provenance. Some of the later sands have conglomeratic bases and are interpreted as channelised fan deposits. Sequence 7 is late Thanetian in age and corresponds to Stewart's "Impoverished Agglutinant Assemblage" biozone.

Sequence 8

Sequence 8 has a wedge-like form, thinning towards the east of the region, and includes the upper part of the Dornoch Formation and the Beauly Formation of Deegan & Scull (1977). The sequence is an overall coarsening-up unit with lignites near the top (Beauly Formation). The lower mud-rich unit correlates with pro-delta and lower slope deposition, grading upwards into slope sands and muds into distributary channel sands and finally delta-plain lignites. Only a single delta system is represented. Eastwards of the final progradational slope and into the Central North Sea, the sequence is represented by a veneer of basinal muds which are older than the Sele Formation of Deegan & Scull (1977). This is at variance with the views of Rochow (1981), Knox *et al.* (1981) and Mudge & Bliss (1983) who correlate the deltaic Moray Group with the Sele Formation. Sequence 8 is of latest Thanetian age with a microfauna consisting of diatoms (*Coscinodiscus* spp. Zone of Stewart and NSP3 Zone of King, 1989). Foraminifera are absent.

Sequence 9

The top of sequence 9, which is regionally widespread, is picked on a prominent seismic event corresponding to the top of the volcanic ash marker of the Balder

Formation. An upward change from grey laminated marine mudstones to greenish blue tuffaceous silty mudstones and banded ash layers, corresponds to the Sele/Balder Formation boundary. In the South Viking Graben thick submarine fan sandstones occur at the base of the Sele Formation and within the Balder Formation, the latter above a tuffaceous mudstone interval which correlates with pyroclastic phase 2b of Knox & Morton (1983). Both fan sands originate from the Fladen Ground Spur and probably rework older sand sequences. Sequence 9 is of Early Eocene age and yields a diatom microfauna characterised by Stewart's zonal index taxon *Coscinodiscus* sp.*1* (equivalent to Zone NSP4 of King, 1989). Stewart's palynological zonation indicates that the base of sequence 9 lies at, or very close to, the Palaeocene - Eocene boundary.

Sequence 10

Sequence 10 comprises a lower lithostratigraphic unit of reddish brown mudstone overlain by a pale grey mudstone. The red mudstone yields red stained early Ypresian planktonic foraminifera (Subzone NSP5a of King, 1989) (which indicates a possible equivilancy with the Rosnaes Clay Formation of Denmark), together with calcareous benthonic and agglutinated foraminifera. This suggests that the transgressive event marked by the base of this sequence saw the reintroduction of normal marine environments into the area.

The upper boundary of sequence 10 is a major regional unconformity that signifies the end of the entire Early Palaeogene depositional system. The Late Palaeocene systems were no longer influenced by Mesozoic structural trends that formed the principle constraint for Early Palaeogene sedimentation.

Reconciliation of Stewart's coastal-onlap curve for the Central North Sea Palaeocene with the global curve of Haq *et al.* (1988) (see Text Figure 14) for the same interval is not easy. This is perhaps to be expected bearing in mind the criticisms of the Haq curve that have been put forward previously. Stewart does not recognise the major sea-level rise recorded during the earliest Danian on the Haq curve. However, this may be in part due to the general absence of sediments of this age across much of the North Sea area. His earliest Palaeocene "highstand system" (i.e. flooding event) occurs in the basal Thanetian and *may* correspond to a so-called minor condensed section near this time on the Haq curve. Stewart subsequently recognises two further "highstand systems" approximately occurring during the mid and latest Thanetian. The earliest of these probably coincides with a so-called major condensed section on the Haq curve and the latter with either one (or perhaps encompassing both) of two minor condensed sections occurring very close together near the top of the Thanetian. The highstand recorded by Stewart in the Ypresian *may*

correspond to either a major or a minor condensed section recorded in the lower Ypresian on the Haq curve.

However, as discussed in Chapter 2, the opening of the North Atlantic during the latest Palaeocene / Early Eocene and the associated tectonic repercussions, must have had significant effects on sequence construction and local sea-level changes in the North Sea Basin and deviation from the "global eustatic curve" of Haq may, therefore, be expected. How far those influences may or may not have extended into the study area of this work (i.e. south Central and Southern North Sea) is unclear however, and much will depend on the results (if any) of future work.

The application of Stewart's scheme to this study is indeterminable as the author has not had access to the seismic cross sections and lithological information necessary to approach the problem. Also, the biostratigraphic sampling interval utilised in this study (average 30 foot samples) is insufficiently closely spaced to afford the resolution necessary. Nevertheless, the faunal compositions encountered during this study may help to throw some light on the types of depositional environments which prevailed during the Early Tertiary in the southern part of the North Sea. If, as the present author believes, the primary control on Early Palaeogene sedimentation in the Southern North Sea is sea levels governing shoreline position then this may at least support Stewart's overall conclusion (page 575) that:

> *"While local subsidence played an important role in controlling the distribution of Late Danian - Early Ypresian sediment in the North Sea Basin as reported by Morton (1979) and Knox et al. (1981), the overriding control of Early Palaeogene sedimentation is considered to be fluctuation of sea level, on at least a regional scale."*

More recently, a major demonstration of the "practical" aspects of the sequence stratigraphic concept has been illustrated by Neal *et al.*, 1994, for the Palaeogene of northwest Europe. Drawing heavily on mainly palynological and nannofossil data with unfortunately only limited recourse to foraminiferal evidence, they have constructed an integrated sequence stratigraphic framework for the region based on well logs, seismic, biostratigraphic (using the graphic-correlation method of Shaw, 1964, and Miller, 1977) and lithological information. This paper only appeared during the final phase of this thesis' completion and is not discussed fully although Neal *et al.*'s main conclusions are outlined below.

Much of the data for Neal *et al.'s* work came from areas in the North Sea to the north of the study area herein (i.e. U.K. quadrants 20, 21, & 22 and further north), although correlation was made with some Danish boreholes. Consequently, some of the conclusions drawn are not strictly applicable to the study area herein but are regionally significant.

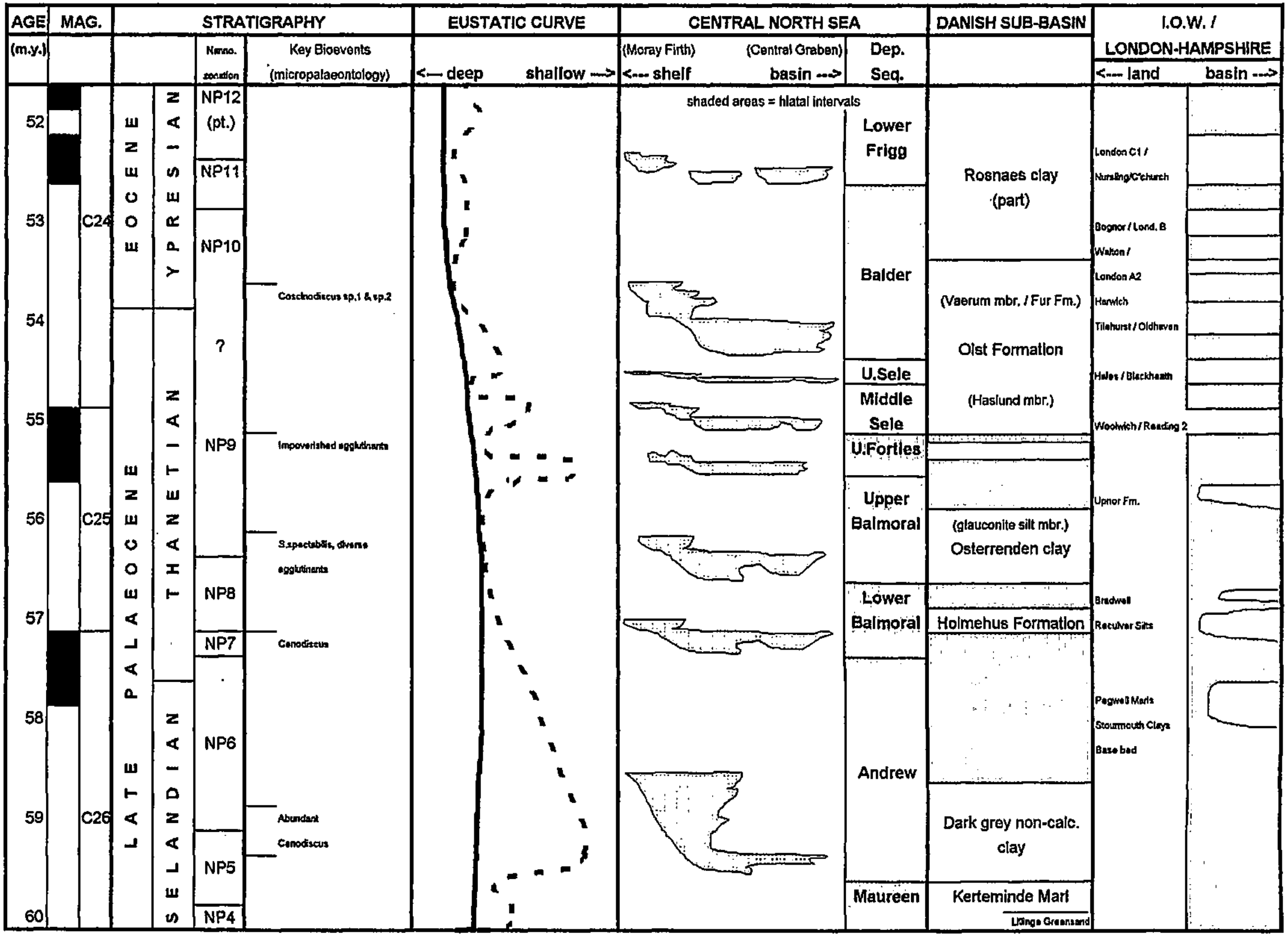
The overall conclusion (Neal *et al.*, 1994, p.75) states that:

> *"...sedimentation in the Central North Sea [Palaeogene] occurs as a series of punctuated depositional pulses separated by time-correlative biostratigraphic data terraces, referred to as hiatal intervals."*

These hiatal intervals correspond to persistent seismic reflectors and are therefore significant sequence stratigraphical events. However, they also indicate that not all of these sequence boundaries are resolvable by the graphic correlation method.

An <u>extraction</u> of the more significant information from Neal *et al.*, 1994, is shown in Text Figure 16. Some of the more significant differences between their interpretations (specifically those referring to micropalaeontological data) and those used herein include the position of the *Cenosphaera lenticularis* highest occurrence and subsequent downhole influx events, which Neal *et al.* (referring to the taxon as *Cenodiscus*) place within their so-called Andrew Depositional Sequence. However, Mudge & Copestake (1992) (as followed here) place these events at the top of the Maureen Formation. Neal *et al.* also split the Late Palaeocene into an upper Thanetian and lower Selandian stage cf. Thanetian which is used herein to refer to the entire Late Palaeocene interval.

Neal *et al.*, 1994; figure 18, p.76-77 (see Text Figure 16 here) also graphically shows the relatively small amount of time during the Palaeocene actually represented by preserved rock strata in northwest Europe (i.e. less than 50%).



Text Figure 16 Palaeogene sequence stratigraphy of the North Sea area (after Neal *et al.*, 1994)

7.Biostratigraphy

7.1.Introduction

The principal unit of biostratigraphy is the "Zone" defined as: "...any rock stratum which can be precisely defined in terms of palaeontological characters or properties." (Whitten & Brooks, 1972). Several types of biostratigraphic zone are in use (see Hedberg, 1971) or the concept of the "Palaeontological Datum" or "bioevent" (e.g. the first evolutionary appearance of the genus *Orbulina* to define the base of the Middle Miocene) can also be used. References to the principles of biostratigraphy can be found in Hedberg (1971) and Holland *et al.* (1978).

One of the most useful tools in microbiostratigraphy are the planktonic foraminifera. They have (essentially) a near worldwide oceanic distribution, though normally within certain latitudinal belts, and are unaffected by local sedimentary environmental factors. Their evolution is often rapid and can lead to many easily distinguishable types in a vertical sequence. They do, however have certain limitations in that they are inferior numerically to benthonic organisms in shallow waters and are often absent in those areas. For a detailed treatment regarding the uses of planktonic foraminifera in microbiostratigraphy see Stainforth *et al.* (1975).

Benthonic foraminifera are also beginning to make inroads into microbiostratigraphy and provide useful (if perhaps less detailed) results, particularly in sequences where planktonic organisms, including planktonic foraminifera, are few or absent. Their one main limitation however, is their susceptibility to facies controls which often leads to different, though contemporaneous benthonic microfaunal assemblages in the same basin.

Another principle of biostratigraphic correlation (particularly for planktonic organisms) is that the boundaries of biostratigraphic zones should be based (as often as possible) on the evolutionary first appearance of a fossil taxon in the stratigraphic record. Due to the potentially global distribution of planktonic organisms because of the lack of physical barriers in the surface waters of the world's oceans, the evolutionary inception of any new species should (at least in geological terms) be practically instantaneous. Indeed, the majority of formal planktonic foraminiferal zonation schemes outlined below follow this principle.

Unfortunately, because of the problems associated with "caving" in borehole ditch cutting samples (see Chapter 4) the first evolutionary appearance of any taxa recorded in such samples is often artificially lowered; i.e. a species will seem to appear in the stratigraphic

record earlier than it does in reality. Therefore, since the early 1970's in the North Sea, zonation schemes have been formulated which, when possible, rely on the evolutionary last appearance of a taxon. This is, in effect, the "extinction" of the particular taxon, which is more reliably found in borehole material as it is highly unlikely that borehole material can cave upwards unless reworked into stratigraphically higher levels by geological processes.

7.2.Established Biostratigraphic Zonations

7.2.1.Planktonic

Most of the early biostratigraphic work on Early Tertiary sediments took place on Trinidad, West Indies, due to the presence of an almost uninterrupted sequence of deep marine shales ranging from the Early Cretaceous to the Late Miocene.

The first Palaeocene investigations in the area were those of Brönnimann (1952) who examined the Soldado, Lizard Springs and Navet Formations. Formal Zones were later erected by Bolli (1957a), 5 of which he regarded as Palaeocene (the Lower Lizard Springs Formation) and 3 from the Early Eocene (Upper Lizard Springs Formation):

Globorotalia aragonensis Zone	Early Eocene
Globorotalia formosa formosa Zone	
Globorotalia rex Zone	
Globorotalia velascoensis Zone	Palaeocene
Globorotalia pseudomenardii Zone	
Globorotalia pusilla pusilla Zone	
Globorotalia uncinata Zone	
Globorotalia trinidadensis Zone	

TABLE 7.1: Planktonic foraminiferal zonation of the Early Tertiary of Trinidad (after Bolli, 1957a)

Bolli achieved some success when attempting to correlate his Trinidad Zones with other Palaeocene - Early Eocene intervals worldwide (Venezuela, Gulf Coast, Mexico, Peru, Egypt, Tunisia, Sweden, Denmark and Bavaria).

Almost contemporaneously with Bolli, Loeblich & Tappan (1957a,b) were attempting the same exercise on the Gulf Coast of the United States. They described four zones:

Globorotalia rex Zone		"Ypresian"
Globorotalia angulata Zone	*G.velascoensis / G.acuta / Globigerina spiralis* Subzone	"Landenian"
	G.pseudobulloides Subzone	
Globorotalia compressa / Globigerina daubjergensis Zone		"Danian"
Globotruncana Zone		"Maastrichtian"

TABLE 7.2: Planktonic foraminiferal zonation of the Early Tertiary of the Gulf Coast (after Loeblich & Tappan, 1957a,b)

They also correlated their Zones with other intervals worldwide (North America, Trinidad, England, France, Belgium, Denmark, Egypt and the Soviet Union).

In the Soviet Union, Palaeocene planktonic microbiostratigraphy began much earlier (Subbotina, 1936 and various papers up to 1966) and continued by Morozova (1959, 1960). Language difficulties, not to mention political differences probably made these schemes inaccessible to the American school and little cross-referencing was made. A review of the Soviet literature was made by Berggren (1960c) who concluded that the Soviet scheme was more or less similar to that described elsewhere although the Danian was regarded as Cretaceous in age and the Palaeocene - Eocene boundary was drawn at the base of the *G.velascoensis* Zone rather than at the top as done elsewhere. Nevertheless, this latter feature was followed by Olsson (1960, 1963) from his work on New Jersey material (U.S.A.).

The importance of applying phylogenetic (i.e. evolutionary) principles to Palaeocene planktonic foraminiferal biostratigraphy was first shown by Berggren (1969 & 1971). He referred to a numerical naming system for his 6 Zones covering the Palaeocene - Early Eocene interval (P1 - P6).

Stainforth *et al.* (1975) developed this system further and, in addition to their zonation scheme, illustrated all significant planktonic foraminiferal taxa from the Cenozoic and discussed the arguments for the uses, for and against, of planktonic foraminifera in international biostratigraphy. Although well into its second decade, this work provides useful source material for the identification of planktonic foraminiferal taxa. Stainforth *et al*, 1975, also correlated together all previously published planktonic foraminiferal zonation schemes for the Cenozoic, including those of Soviet workers of that period (Subbotina, 1953, "Anonymous", 1963 and others).

Globorotalia pentacamerata Zone	Early Eocene
Globorotalia aragonensis Zone	
Globorotalia formosa formosa Zone	
Globorotalia subbotinae Zone	
Globorotalia velascoensis Zone	Late Palaeocene
Globorotalia pseudomenardii Zone	
Globorotalia pusilla pusilla Zone	Middle Palaeocene
Globorotalia angulata Zone	
Globorotalia uncinata Zone	
Globorotalia trinidadensis Zone	Early Palaeocene
Globorotalia pseudobulloides Zone	
Globigerina eugubina Zone	

TABLE 7.3: Early Tertiary planktonic foraminiferal zonation
(after Stainforth *et al.*, 1975)

Blow (1969, 1979) refined and added to this scheme and rigorously redefined many of the planktonic foraminiferal zones and discussed in great detail the taxonomic status of many important species. In three large volumes, each species' taxonomy is treated exhaustively and extensive use of Subgenera and Subspecies is made. Blow's zonation encompasses the Latest Cretaceous and the entire Tertiary with a total of 45 zones (2 "M"esozoic, 23 "P"alaeogene and 20 "N"eogene) with all but 3 defined on evolutionary first appearances of taxa:

ZONE		SUBZONE		AGE
P8	*G.(M.) formosa*	P8b	*G.(M.) aragonensis*	Early Eocene "Cuisian"
		P8a	*G.(M.) formosa/lensiformis*	
P7	*G.(A.) wilcoxensis berggreni*			Latest Palaeocene "LONDINIAN"
P6	*G.(M.) subbotinae subbotinae / G.(M.) velascoensis acuta*			
P5	*M.soldadoensis soldadoensis/M. velascoensis pasionensis*			Late Palaeocene "THANETIAN"
P4	*G.(G.) pseudomenardii*			
P3	*G.(M.) angulata angulata*			
P2	*G.(A.) praecursoria praecursoria*			
P1	*G.(T.) pseudobulloides / E.eobulloides simplicissima*	P1b	*G.(T.) compressa compressa / E.eobulloides simplicissima*	Early Palaeocene "DANIAN"
		P1a	*G.(T.) pseudobulloides / G.(T.) archaeocompressa*	
Pα	*G.(T.) longiapertura*			

TABLE 7.4: Phylogenetic planktonic foraminiferal zonation of the Early Tertiary (after Blow, 1969,1979)

Note that Blow had placed the Danian - Thanetian boundary within Zone P2, on the grounds that this is the stratigraphic position of the type Danian in Denmark (Blow, 1979). However, the type Danian is now known to be incomplete with its upper and lower limits being bounded by unconformities. Studies of more complete Danian localities, particularly in France and the U.S.S.R. (see Berggren, 1971) indicate that the boundary should be placed at the top of Zone P2 in agreement with that suggested by Hardenbol & Berggren (1978).

Blow's scheme, however, has only limited potential in North Sea Basin studies because of his emphasis on evolutionary first appearances and his reliance on warm water, keeled taxa which are generally absent in the North Sea Palaeocene due to adverse environmental factors.

The scheme of King (1983, revised 1989) was introduced specifically for the North Sea Basin. 28 North Sea Planktonic (NSP) Zones and/or Subzones exist with the majority based on "tops" (= extinctions = last evolutionary occurrences). The Zones covering the Palaeocene to Early Eocene interval are described below:

NSP6	*Cenosphaera* Zone			Early Eocene "Ypresian"
NSP5		b	*P.wilcoxensis* Subzone	
		a	*S.*ex gr.*linaperta* Subzone	
NSP4	*Coscinodiscus* sp.*1* Zone			Late Palaeocene "Thanetian"
NSP3	Unnamed Zone			
NSP2	"*Cenodiscus*" spp. Zone			
NSP1		c	*G.chapmani* Subzone	Early Palaeocene "Danian"
		b	*G.pseudobulloides* Subzone	
		a	*G.daubjergensis* Subzone	

TABLE 7.5: Planktonic zonation of the Early Tertiary (North Sea)
(after King, 1983, 1989)

Zone NSP 6:	Top defined at the LAD (Last Appearance Datum i.e. "Top") of large spherical radiolaria (*Cenosphaera* spp.). Calcareous fossils are usually rare or absent in this Zone.
Subzone NSP 5b:	Top defined as the downhole reappearance of planktonic foraminifera below Zone NSP 6. The FAD (First Appearance Datum i.e. "base") of *Globanomalina wilcoxensis* (Cushman & Ponton) is near the base of this Subzone.
Subzone NSP 5a:	Top defined as a downhole increase in abundance (to >80% of the assemblage) of *Subbotina* ex gr. *linaperta* (Finlay).
Zone NSP 4:	Top defined as the downhole disappearance of planktonic microfossils and the LAD of *Coscinodiscus* sp.1 and *Coscinodiscus* sp.2.
Zone NSP 3:	Top defined as the FAD ("base") of the *Coscinodiscus* assemblage of Zone NSP 4. Planktonic foraminifera are generally absent.
Zone NSP 2:	Top defined as the LAD of an influx of spherical / lenticular radiolaria (*Cenodiscus* spp.). Planktonic foraminifera are generally absent.

Subzone NSP 1c: Top defined as the downhole reappearance of planktonic foraminifera (e.g. *M.pseudobulloides* (Plummer), *P.compressa* (Plummer), *S.triloculinoides* (Plummer) and *P.chapmani* Parr).

Subzone NSP 1b: Top defined as the FAD of *P.chapmani*.

Subzone NSP 1a: Top defined as the LAD of *G.daubjergensis* (Brönnimann).

7.2.2.Benthonic

As stated in the Introduction (Chapter 1) it was benthonic foraminifera of Palaeocene age that were first utilised in the attempted correlation between the oil bearing horizons in the adjacent boreholes of the Potok and Krosno wells in the Polish Carpathians (Grzybowski, 1898). This innovative attempt was not received enthusiastically by Grzybowski's contemporaries due to the belief that the group Grzybowski used, agglutinating foraminifera, was unsuitable because of the long stratigraphic ranges of the majority of the genera.

Later, working in the same area, Geroch (1959, 1960) characterised 9 "beds" ranging from Valanginian to Eocene times each characterised by different agglutinated assemblages. Morgiel & Olszewska (1981) expanded this to 13 assemblage zones and the scheme was further refined by Geroch & Nowak (1983) who extended the scheme to include the Tithonian (Late Jurassic) and equated their zones to the established European stages.

Several attempts were also made to use the group outside the Polish Carpathians e.g. Grun (1969) - Austria; Samuel (1977) -Czech Carpathians and Verdenius & Van Hinte (1983) - Norwegian and Greenland Seas.

Gradstein & Berggren (1981) described in detail the agglutinated microfauna from several boreholes in the North Sea and Labrador Sea, though without referring to a specific zonal scheme. Kaminski *et al.* (in press) have examined the agglutinating foraminifera from the same interval in Trinidad and noticed many similarities with the European faunas.

Doppert & Neele (1983) formulated a zonal scheme based on calcareous benthonic foraminifera for the marine Palaeogene of the Netherlands which also has applicability in the North Sea offshore:

	ZONE	AGE	
FI	*Anomalina ypresiensis / Gaudryina hiltermanni*	Lower Eocene	
FJ	*Bulimina trigonalis / Cibicides proprius*	Palaeocene	Landenian, Heersian & partly Montian
FK	*Pararotalia globigeriniformis / Rotalia saxorum*	Palaeocene	partly Montian & Danian

TABLE 7.6: Foraminiferal zonation of the Early Tertiary of the Netherlands. (after Doppert & Neele, 1983)

King (1983, revised 1989) proposed a zonation scheme for the Tertiary of the North Sea Basin based on benthonic foraminifera ("NSB" Zones) which ran in conjunction with his planktonic zonation scheme described above. A total of 30 Zones and Subzones were described and the Zones covering the Palaeocene to Early Eocene interval are described below. It should be noted that in the 1983 version, King used both calcareous and agglutinated taxa in his NSB scheme. However, in 1989, a third scheme based wholly on agglutinated taxa ("NSA" Zones) was erected. NSB 4 and NSB 1 were previously (1983) defined on agglutinating assemblages and have now been transferred to the NSA scheme described later.

	ZONE		SUBZONE	AGE
NSB4	Unnamed			Early Eocene "Ypresian"
NSB3		b	*Bulimina* sp.A	
		a	*G.hiltermanni*	
NSB2	Unnamed			Late Palaeocene "Thanetian"
NSB1		c	*B.trigonalis*	
		b	*S.beccariiformis*	
		a	*T.selmensis*	Early Palaeocene "Danian"

TABLE 7.7: Benthonic foraminiferal zonation of the Early Tertiary (North Sea) (after King, 1983, 1989)

Zone NSB 4: Top defined the FAD of *Neoeponides karsteni* (Reuss) which ranges from the zone above and younger. No suitable calcareous index taxa are available (King, 1989) and calcareous assemblages are poor.

Subzone NSB 3b: Top defined on the LAD of *Gaudryina hiltermanni* Meisl, and the downhole reappearance of calcareous benthonic taxa. *Bulimina* sp.A and *Cancris* sp.*A* (both of King, 1989) are restricted to this Zone.

Subzone NSB 3a: Top defined as the FAD of *Bulimina* sp.A (King) and *Cancris* sp.A (King). No species are restricted to this Subzone.

Zone NSB 2: This Zone is characterised by the general absence of calcareous foraminifera except in shallow waters (the "Inner Sublittoral Facies" of King, 1983).

Subzone NSB 1c: Top not well defined but typical taxa include *Bulimina midwayensis* Cushman & Parker, *Stensioeina beccariiformis* (White) and *Stilostomella midwayensis* (Cushman & Todd).

Subzone NSB 1b: Top defined by the downhole increase in abundance and diversity of calcareous benthonic taxa.

Subzone NSB 1a: Top defined by the FAD of *B.midwayensis*.

15 Zones and Subzones based on agglutinating species ("NSA" Zones) were formulated by King (1989) to reflect the importance of the group in the North Sea so-called "*Rhabdammina* biofacies" (see below).

	ZONE		SUBZONE	AGE
NSA4		b	*R.amplectens*	Early Eocene "Ypresian"
		a	*T.plummerae*	
NSA3	Unnamed			
NSA2	*V.subeocaenus*			Late Palaeocene "Thanetian"
NSA1		b	*T.ruthvenmurrayi*	
		a	*S.spectabilis*	
NSB1a=	Unnamed unit equal to NSB1a Subzone			Early Palaeocene "Danian"

TABLE 7.8: Agglutinated foraminiferal zonation of the Early Tertiary (North Sea) (after King, 1989)

Subzone NSA 4b: Top defined by the consistent downhole presence of *Reticulophragmium amplectens* (Grzybowski).

Subzone NSA 4a: Top defined by the LAD of consistent *Textularia plummerae* Lalicker (= *Spiroplectammina navarroana* Cushman herein).

Zone NSA 3: Top defined by the FAD of *R.amplectens* and is characterised by a low-diversity assemblage.

Zone NSA 2: Top not defined but this Zone is characterised by the absence of "*Rhabdammina* biofacies" type taxa. However, *V.subeocaenus* (Wick) and *T.papillata* Brady are probably restricted to this Zone.

Subzone NSA 1b: Top defined by the downhole reappearance of a diverse and abundant "*Rhabdammina* biofacies" assemblage. The LAD of "typical" *S.spectabilis* (Grzybowski) also occurs at this level.

Subzone NSA 1a: Top defined by the FAD of *Trochammina ruthvenmurrayi* Cushman & Renz.

Unnamed Interval: Agglutinating foraminifera are absent throughout this interval and therefore was not included in the NSA scheme of King (1989).

King (1989) also calibrated his North Sea zonal schemes with the standard stratigraphic scale of Berggren *et al.*, 1985), with the majority of the calibrations made using dinoflagellate, planktonic foraminiferal and nannofossil data from onshore sequences. A summary of this is given below.

- Calibration of Zones NSP 7-5 and NSB 5a-3 to the NP and P Zones was based on King (1983), Heilmann-Clausen *et al.* (1985) and Hooyberghs (1983).

- Calibration of Zone NSB2 (Balder and Sele Formations and their corresponding onshore "Ash Series") is difficult because of the lack of calcareous fossils. The NSB2/NSB3 (NSP4/NSP5) junction corresponds to the short dinoflagellate Zone D6a (*Wetzeliella astra* Zone) is at the top of the Balder Formation. The *W.astra* Zone corresponds approximately to the NP9/NP10 boundary in the North Atlantic (Costa & Muller, 1978). However, Knox (1984) using North Atlantic nannoplankton data and ash correlations places this boundary (in effect the Palaeocene/Eocene boundary) at the base of the Sele Formation. King (1989) on the other hand, places the boundary at the Sele/Balder Formation boundary.

- Taking King's correlation, the base of the Sele Formation (NSB2/NSP4) corresponds to the dinoflagellate Zone D5 (*Apectodinium hypercanthum* Zone). In onshore sequences, nannoplankton characteristic of Zone NP9 have been found in the lower part of Zone D5.

- The upper part of dinoflagellate Zone D4 (*Alisocysta margarita* Zone) can be correlated with NP8. Therefore The NP8/NP9 boundary corresponds approximately to the NSB1/NSB2 boundary (the base of the Sele Formation).

- Zone NSP3 can be correlated with the lower part of the Thanet Beds in England (Heilmann-Clausen, 1985) which was recently assigned to NP6 or NP7 (Siesser *et al.*, 1987).

- Zone NSP2 can be identified in Denmark (e.g. the Kerteminde Marl) and has been dated as upper NP4 or lower NP5 (Thomsen & Heilmann-Clausen, 1983). *Planorotalites chapmani* (P3 - P6) is also recorded from this Zone and from Denmark. Note that Hansen (1979) regards the Kerteminde Marl as younger - lying within Zones NP 6-8 in Denmark, i.e. the top of NSB1 as shown above.

- *Morozovella angulata* (Toulmin) (P3 to lower P4) and *Morozovella uncinata* (Bolli) (P2 - lower P3) have also been recorded from the North Sea. This indicates a correlation between NSP1c and P3.

A summary of the primary microfaunal "events" ("tops", "bases" and "influxes") within the Early Tertiary of the North Sea are indicated, along with King's tripartite zonation schemes (NSP, NSB and NSA) and approximate correlation with the sequence stratigraphic scheme of Stewart (1987) is shown in Text Figure 17.

In addition to the biostratigraphic application of King's zonations, he also recognised 3 depth related benthonic foraminiferal biofacies within the North Sea Cenozoic (King, 1983):

1) **"Inner sublittoral biofacies"** - Characterised by elphidiids, polymorphinids, miliolids, attached cibicidids and rotaliids (including larger rotaliids e.g. *Nummulites* in the Eocene). King suggests water depths between 0-50m for this biofacies.

2) **"Outer sublittoral - epibathyal biofacies"** - Two depth related subfacies can be distinguished:

a) Significant numbers of large nodosariids, valvulineriids, bolivinids, large buliminids and (in the Neogene) cassidulinids. This biosubfacies is compared with the "Midway type" assemblage of Berggren & Aubert (1975) and water depths of between 50-200m are suggested.

b) An association of pleurostomellids, stilostomellids, small gyroidinids, *Pullenia* and *Oridorsalis*. Specimens are generally smaller than those of subfacies 2a. This biosubfacies is compared with the 'Velasco type' assemblage of Berggren & Aubert (1975) and depths of >200m are suggested.

3) **"*Rhabdammina* biofacies"** - Dominated by, or exclusively composed of, non-calcareous 'flysch type' agglutinating foraminifera such as Astrorhizacea, Ammodiscacea and cyclamminids. Calcareous foraminifera may be present but are usually small and often affected by post mortem dissolution. This biofacies occurs in the deeper parts of the North Sea Basin and replaces biosubfacies 2b in these areas. Water depths of at least 200m are suggested.

Charnock & Jones (1990) published extensive notes on the agglutinated foraminifera from the Palaeogene of the North Sea and include much useful data on the stratigraphic ranges of such taxa although they did not construct a zonal scheme based on this group.

More recently, a major synthesis of the Northwest European Tertiary Basin has been published by Vinken (compiler), 1988. This has produced another zonation scheme for the whole of Northwest Europe again split into separate planktonic and benthonic foraminiferal schemes. However, these are less detailed than the schemes of King (1983, 1989):

PLANKTONIC	PLANKTONIC TAXA	BENTHONIC	AGE
NPF4	*S.patagonica* T.R.Z.	B3	Early Eocene
NPF3	*S.triangularis* P.R.Z.		
NPF2	*S.triloculinoides / M.angulata* P.R.Z.	B2	(Mid)-Late Palaeocene
		B1	Early Palaeocene
NPF1	*G.daubjergensis* P.R.Z.		

TABLE 7.9: Foraminiferal zonation of the Early Tertiary (NW Europe)
(after various authors in Vinken, 1988)

However, the most recent schemes published integrate lithostratigraphic and sequence data with biostratigraphic "events" (i.e. microfossil marker horizons) rather than "zones". These schemes (Mudge & Copestake, 1992 and Knox & Holloway, 1992) are discussed in Chapter 6.3 above although key micropalaeontological bioevents for the North Sea Lower Palaeogene, incorporating these and other important datums, are shown in Text Figure 17.

Mudge & Copestake (1992) recognise 7 Micropalaeontological events (M1 - M7) and 3 Palynological events (P1 - P3) from the Outer Moray Firth. Some of these events can, however, be applied elsewhere in the North Sea Basin. In addition to these M and P events, Knox & Holloway (1992) recognise additional key bioevents. A composite list of these events are shown below in downhole order with the author's' respective taxonomies used:

	Top *A.diktyoplokus*	Eocene/Oligocene boundary
	Top *G.index*	Late Eocene
	Top *S.*aff.*spectabilis*	Mid/Late Eocene
	Top *E.ursulae*	Early/Mid Eocene boundary
	Influx *Cenosphaera* spp.	Early/Mid Eocene
	S.linaperta acme	Early Eocene
M7	Top *Coscinodiscus* sp.1	Early Eocene
	D.oebisfeldensis acme	Early Eocene
M6	*Coscinodiscus* sp.4 acme	Earliest Eocene
P3	*A.augustum* acme	Palaeocene/Eocene boundary
M5	Top impoverished agglutinants	Late Thanetian
P2[5]	Top *A.margarita*/*A.*cf.*senonensis*	Thanetian
M4	Top diverse agglutinants	Thanetian
	Top *A.gippingensis*	Thanetian
P1	Top *P. pyrophorum*	Early Thanetian
M3	Top *C. lenticularis*	Earliest Thanetian
M2	Top *G.trivialis*/*G.*cf.*compressa*	Late Danian
	S.beccariiformis acme	Late Danian
	Top *G. pseudobulloides*	Late Danian
M1	Top *G.simplicissima*/*G.*aff.*trivialis*	Early Danian (=P1 Zone)
	Top *S.inornata*	Early Danian

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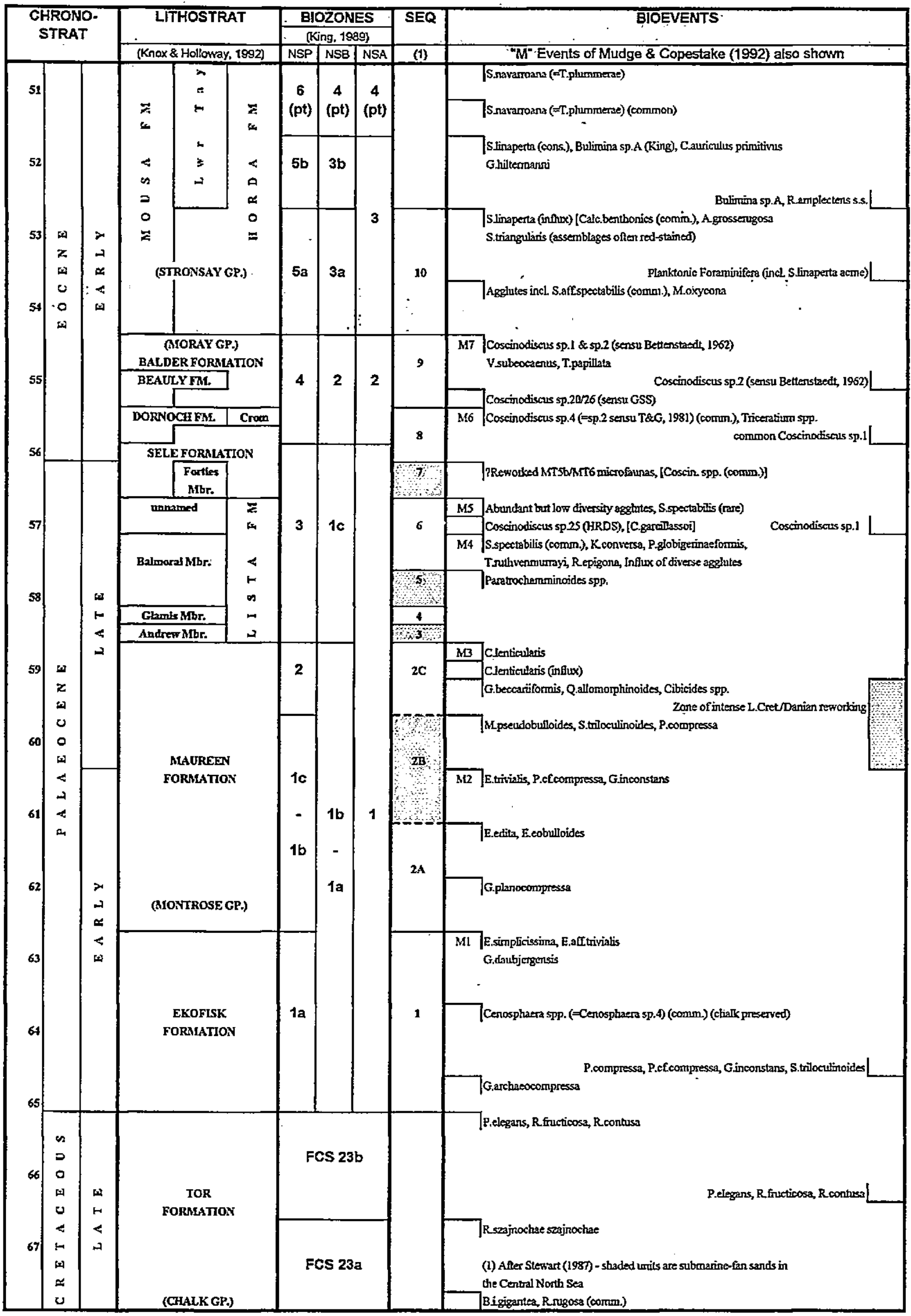
[5] Coincident with event M4

Text Figure 17: Key micropalaeontological bioevents in the Lower Palaeogene of the North Sea



(1) After Stewart (1987) - shaded units are submarine-fan sands in the Central North Sea

8.Systematic Descriptions

8.1.Introduction

The vast majority of micropalaeontological specimens recorded in this study belong to the Order Foraminiferida. The generic and suprageneric classification of the foraminifera used in this thesis is that of Loeblich & Tappan (1988). Reference is also made to other works where necessary. Species are arranged in alphabetical order within each genus. Systematic descriptions of other, less common microfossil groups recorded (e.g. ostracods, diatoms etc.) follow on from the foraminifera but are listed in generic order only with no attempt at a full hierarchical classification.

This thesis is not primarily a taxonomic treatment and exhaustive synonomy, reference lists and detailed descriptions are not given as the majority of species described herein are well known and documented. In most cases, reference lists consist of the initial reference to the species in the literature and significant references concerned with the Northwest European area and/or which contain good source material for further information.

Where the species recorded is well known and documented, an illustration / photograph is not provided in this thesis. In this instance, a full reference to suitable illustration(s) is given.

Reference works particularly useful for identification purposes (of the foraminifera) include: Berggren (1964); Berggren & Aubert (1975*); Blow (1979*); Brotzen (1948); Charnock & Jones (1990*); Doppert & Neele (1983*); El-Naggar (1966); Gradstein & Berggren (1981*); Hart *et al.* (1989*); Haynes (various 1956*-1958*); Hofker (1966*); Koch (1977*); King (1983* & 1989*); King *et al.* (1989*); Loeblich & Tappan (1957); van Morkhoven *et al.* (1986*); Murray *et al.* (1989*) and Stainforth *et al.* (1975*); Swiecicki (1980*)[6]. Those marked (*) contain good quality illustrations and/or descriptions of the taxa.

The number of references recommended for illustration sources has been kept, where possible, to a minimum, and most have been commonly accepted as standard reference works on the subject.

Full species descriptions are, again, not provided as the majority of taxa recorded are well known. A brief summary of the diagnostic features of each species is, however, included.

---

[6] Unpublished PhD thesis

This is followed by general remarks concerning, for example, salient taxonomic points, variation, comparisons with similar forms and palaeoenvironmental significance. This is, in turn, followed by a statement on the stratigraphical range of each taxon and, unless indicated, refers to the published or inferred stratigraphical range of the taxon *in the Northwest European area only.*

Finally, a summary statement on the taxon's distribution within the material studied herein is given in separate tabular form for off- and on-shore localities. Relative abundances are quantified thus:

no entry	:	taxon not recorded at that locality
?	:	taxon only questionably identified at that locality
rare	:	less than c.10 specimens recorded at that locality
mod.comm.	:	c.10-50 specimens recorded at that locality
common	:	c.50-100 specimens recorded at that locality
v.common	:	c.100-200 specimens recorded at that locality
abundant	:	more than c.200 specimens recorded at that locality

Full sets of species distribution data are presented on a series of charts enclosed at the end of this volume. The palaeontological distribution data for Shell/Esso offshore wells and onshore B.G.S. boreholes are presented on charts generated by StrataData Ltd.'s "StrataBugs" palaeontological database system. Charts for onshore field sections were produced on "Excel" spreadsheets.

8.2.The Foraminifera

Phylum PROTISTA
Subphylum SARCODINA
Class RHIZOPODEA
Order FORAMINIFERIDA Eichwald, 1830
Suborder TEXTULARIINA Delage & Herouard, 1896
Superfamily ASTRORHIZACEA Brady, 1881
Family BATHYSIPHONIDAE Avnimelech, 1952
Genus *Bathysiphon* Sars, 1872
***Bathysiphon discreta* (BRADY)**
Recommended source for illustration:
Gradstein & Berggren (1981) pl.I, figs 4-6, 7-10

1881 *Rhabdammina discreta* BRADY p.48 no figs
1960 *Rhabdammina discreta* Brady: GEROCH p.36
1981 *Bathysiphon discreta* (Brady):GRADSTEIN & BERGGREN p.240 Var A pl.1 figs 4-6 Var B pl.1 figs 7-10
1989 *Bathysiphon eocenicus* Cushman & Hanna: KING p.454 fig.9
1989 *Bathysiphon nodosariaformis* Subbotina: KING p.454 pl.9.1 fig. 10
1990 *Rhabdammina discreta* Brady: CHARNOCK & JONES p.152, pl.1, fig.25, pl.13, fig.23

DIAGNOSIS: Test agglutinated, short, tubular, slightly curved to straight, occasionally constricted, wall thick and finely to coarsely agglutinated.

REMARKS: Gradstein & Berggren (1981) describe two versions of this species differentiated by coarse or finely agglutinated wall structure although they indicate transitional forms do occur. The author could not find any stratigraphic reason why the two variations should be separated. The two taxa listed by King, 1989, *B.eocenicus* and *B.nodosariaformis*, are equivalent to *Bathysiphon* sp.'B' and sp.'A' of Gradstein & Berggren, 1981, respectively. The fact that, as King admits, most specimens of *Bathysiphon* and indeed other "tubular" genera, are recovered as fragments, makes their taxonomic assignation (i.e. as *Rhabdammina* or *Bathysiphon*) somewhat difficult (see also Charnock & Jones, 1990).

RANGE: Late Cretaceous to Miocene in the North Sea (King, 1989) although the species has been recorded (under various names) in the literature from a variety of long-ranging stratigraphical intervals.

A low diversity assemblage of this species, plus others including *Rhizammina indivisa*, is characteristic of Bioevent M5 of Mudge & Copestake. 1992. This event is of latest Palaeocene age and marks the top of the Lista Formation.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	mod.comm	**49/24-3**	rare
29/25-1	mod.comm.	**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Family RHABDAMMINIDEA Brady, 1884
Genus *Rhabdammina* Brady, 1897
***Rhizammina indivisa* BRADY**
Recommended source for illustration:
Gradstein & Berggren (1981) pl.I, figs 1-3

1884 *Rhizammina indivisa* BRADY p.277, pl.29, figs 5-7
1981 *Rhizammina indivisa* Brady: GRADSTEIN & BERGGREN p.240, pl.I, figs 1-3

DIAGNOSIS: Test short, tubular and curved. Wall normally coarsely agglutinated.

REMARKS: Distinguished from *Bathysiphon discreta* by the curved nature of the tubular test.

RANGE: A very long-ranging taxon (probably Mesozoic - Recent). In the North Sea area its stratigraphical distribution is probably the same as for *Bathysiphon discreta* (i.e. Late Cretaceous - Miocene).

A low diversity assemblage of this species, plus others including *Bathysiphon discreta*, is characteristic of Bioevent M5 of Mudge & Copestake. 1992. This event is of latest Palaeocene age and marks the top of the Lista Formation.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	common	**49/24-3**	
29/25-1	mod.comm.	**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily AMMODISCACEA Reuss, 1862
Family AMMODISCIDAE Reuss, 1862
Genus *Ammodiscus* Reuss, 1862
***Ammodiscus cretaceus* (REUSS)**
Recommended source for illustration:
Gradstein & Berggren (1981) pl.II, figs 12-13

1845 *Operculina cretacea* REUSS p.35 figs.64-65

1922 *Ammodiscus glabratus* CUSHMAN & JARVIS p.86 pl.12 fig.6

1981 *Ammodiscus cretaceus* (Reuss): GRADSTEIN & BERGGREN p.241 pl.2 figs 12-13

1989 *Ammodiscus cretaceus* (Reuss): KING p.452 pl.9.1 fig.3

1990 *Ammodiscus cretaceus* (Reuss): CHARNOCK & JONES p.154, pl.2, figs 1-3, pl.14, fig.3

DIAGNOSIS: Test free, agglutinated, composed of a singular planispirally coiled circular tube of about 8-10 whorls increasing in diameter very slowly. The surface may show fine, radial striations.

REMARKS: *A.cretaceus* differs from *A.planus* in its larger size and more numerous whorls and from *A.peruvianus* in its circular outline. This species is fairly common in the North Sea wells studied but rare in onshore sections. Its long range (Jurassic -Recent) limits its value in biostratigraphy. An extensive taxonomy of this species is discussed by Charnock & Jones, 1990.

RANGE: Jurassic - Recent (Santonian - Early Oligocene in NW Europe according to King, 1989 but recorded in much older strata by various other workers).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	common	**49/24-3**	rare
29/25-1	common	**49/20-2**		**49/24-4**	rare
44/2-1	mod.comm.	**49/24-2**		**49/25-2**	mod.comm.
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Ammodiscus peruvianus BERRY

Recommended source for illustration:
Gradstein & Berggren (1981) pl.II, figs 14-15

1928 *Ammodiscus peruvianus* BERRY: p.342 pl.27

1981 *Ammodiscus peruvianus* Berry: GRADSTEIN & BERGGREN p.241 pl.2 figs.14-15

1988 *Ammodiscus peruvianus* Berry: KAMINSKI *et al.* p.185, pl.3, figs 11-12

DIAGNOSIS: An *Ammodiscus* species with an elliptical outline with approximately 6-7 whorls.

REMARKS: Several authors (including Charnock, 1983 and Charnock & Jones, 1990) have regarded this form as being deformed specimens of *A.cretaceus*. However, if this were the case one would expect deformations in various planes of orientation which does not seem to occur.

RANGE: Probably similar to that of *A.cretaceus* i.e. Santonian - Early Oligocene in NW Europe.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1	mod.comm.	**49/20-2**		**49/24-4**	
44/2-1	mod.comm.	**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Glomospira* Rzehak, 1885

Glomospira charoides (JONES & PARKER)

Recommended source for illustration:
Gradstein & Berggren (1981) pl.III, figs 5-7

1860 *Trochammina squamata* JONES & PARKER var. *charoides* p.304

1896 *Ammodiscus charoides* (Jones & Parker): GRZYBOWSKI p.280 figs.39-43

1928 *Glomospira charoides* (Jones & Parker) var. *corona*: CUSHMAN & JARVIS p.89, pl.12, figs.9-11

1960 *Glomospira charoides* (Jones & Parker): GEROCH p.46 pl.4 figs.1,2,5

1981 *Glomospira charoides* (Jones & Parker):GRADSTEIN & BERGGREN p.243 pl.3 figs.5-7

1989 *Glomospira charoides* (Jones & Parker): KING p.455 pl.9.1 fig.17

1989 *Glomospira gordialis* Gradstein & Berggren: KING p.455

1990 *Usbekistania charoides* (Jones & Parker): CHARNOCK & JONES p.158, pl.2, figs 17-19, pl.14, fig.13

DIAGNOSIS: Test free, agglutinated. Spherical to ellipsoidal in gross shape. A regular coil with the final coil sometimes developed on the top part of the test like a small "crown". The wall is very finely agglutinated.

REMARKS: The main part of the test resembles the calcareous algae *Chara* from which this species derives its name. Cushman & Jarvis (1928) restricted their variation "*corona*" only to those forms possessing the "crown" feature. However, forms lacking this feature have been found in the material studied. It is a fairly common species in the North Sea and Gradstein & Berggren (1981) state that it is rare in the Lower to Middle Eocene sediments in their material. Therefore, this species (where consistent) may be a useful Palaeocene indicator in the North Sea where the "*Rhabdammina* biofacies" is developed. King (1989) regards *G.gordialis* to be synonymous with *G.charoides* citing Kaminski *et al.* (in press) as a source for the recording of observed intergradations between the two end-members in a single population.

Separation of this species as *Usbekistania* (after Suleymanov, 1960 as followed by Charnock & Jones, 1990) from other *Glomospira* spp. has not been followed here.

This species has an extensive bathymetric range of between 85-5779m in the North Atlantic (Charnock & Jones,1990).

RANGE: Early Cretaceous - Late Miocene (King, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	mod.comm.	**49/24-3**	rare
29/25-1	mod.comm.	**49/20-2**		**49/24-4**	rare
44/2-1	common	**49/24-2**	rare	**49/25-2**	mod.comm.
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		rare
Reculver					

Glomospira gordialis (JONES & PARKER)

Recommended source for illustration:
Gradstein & Berggren (1981) pl III, figs 2-3

1860 *Trochammina squamata* JONES & PARKER var. *gordialis* p.304

1896 *Ammodiscus gordialis* (Jones & Parker): GRZYBOWSKI p.284 figs.44-45

1967 *Glomospira gordialis* (Jones & Parker): GEROCH p.46 pl.4 figs

1981 *Glomospira gordialis* (Jones & Parker):GRADSTEIN & BERGGREN p.246 pl.3 figs.2-3

1990 *Glomospira gordialis* (Jones & Parker): CHARNOCK & JONES p.156, pl.2, fig.12, pl.14, fig.9

DIAGNOSIS: Irregularly coiled in a spherical gross test shape with coils often changing the coiling plane. The final coil is usually however, equatorial in aspect and girdles the initial coiled portion. The wall is very finely agglutinated.

REMARKS: This species is distinguished from *G.charoides* by its "Saturn-like" appearance. Gradstein & Berggren (1981) state that the two forms are related through morphological transition stages and King (1989) includes this taxon with *G.charoides* for the same reason. Both taxa are regarded as separate in this study as there appears to be local variation in proportions of one particular "end-member" where both coexist in reasonable numbers.

RANGE: Probably the same as for *G.charoides* i.e. Early Cretaceous - Late Miocene (King, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	rare	**49/24-3**	
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1	mod.comm.	**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Glomospirella* Plummer, 1945

***Glomospirella woodi* HAYNES**

Recommended source for illustration:

King (1989) pl. 9.1, fig.18

1958 *Glomospirella woodi* HAYNES p.59, pl.15 fig 1a-c

?1981 *Glomospira irregularis* (Grzybowski): GRADSTEIN & BERGGREN p.246, pl.III, figs 1,4

1989 *Glomospirella* sp.*A*: KING p.455 pl.9.1 fig.18

DIAGNOSIS: A *Glomospirella* with the initial portion of the test coiled irregularly. Later whorls are coiled planispirally rather like *Ammodiscus*.

REMARKS: This species has been recorded from the Early Eocene of the Labrador Sea (Miller *et al.*, 1982) and from the Late Palaeocene of the North Sea (King, 1989). It may be closely related, if not identical to *Glomospira irregularis* (Grzybowski) which appears to show an even more random coiling pattern. This species has been included within the synonomy of *G.gordialis* by Charnock & Jones, 1990.

RANGE: Palaeocene - Early Eocene.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	?	**49/24-3**	rare
29/25-1	rare	**49/20-2**		**49/24-4**	rare
44/2-1	mod.comm.	**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		mod.comm.	**Stevns Klint**		
Reculver					

Superfamily RZEHAKINIACEA Cushman, 1933

Family RZEHAKINIDAE Cushman, 1933

Genus *Rzehakina* Cushman, 1927

***Rzehakina epigona* (RZEHAK)**

Recommended source for illustration:

Gradstein & Berggren (1981) pl.V, fig. 1

1895 *Silicina epigona* RZEHAK p.214 pl.6 fig.1

1945 *Rzehakina epigona minima* CUSHMAN & RENZ p.24 pl.3 fig.5

1974 *Rzehakina epigona* (Rzehak): HILTERMANN p.36 pl.5 figs.10, 11, 16-18, 21-22, 24, 28. pl.5 figs.9, 10, 14, 15, 31-33

1989 *Rzehakina epigona* (Rzehak): KING p.459 pl.9.2 fig.23

1990 *Rzehakina epigona* (Rzehak): CHARNOCK & JONES p.159, pl.3, figs 1-2, pl.14, fig.14

1990 *Rzehakina minima* (Cushman & Renz): CHARNOCK & JONES p.159, pl.3, figs 3-4, pl.14, fig.15

DIAGNOSIS: Test free, agglutinated and small. The early whorls are coiled streptospirally, later planispirally and involute with 2 chambers per whorl giving an elongate though relatively wide elliptical shape to the test. The test wall is smooth and finely agglutinated. The final chamber develops a slight prolongation towards the aperture.

REMARKS: This species differs from *Rzehakina* sp.1 (Gradstein & Berggren) in its involute rather than evolute test and a rather wider test-width.

Various authors argue for the synonomy or otherwise between *R.epigona* and *R.minima.* E.g. Scott (1961) synonomises the two based on extensive statistical data whereas Charnock & Jones (1990) regard them as separate, based on differences in stratigraphic range. However these two authors quote essentially the same stratigraphic range for the two species (Charnock & Jones, 1990, p. 159 and text figure 3).

RANGE: Campanian - Late Palaeocene (King, 1989). Mudge & Copestake (1992) regard the "top" of this species' range to be partly characteristic of their Bioevent M4. This event is of Late Palaeocene age, occurs within the Lista Formation and can be used to mark the top of the Balmoral Member, especially in the Outer Moray Firth.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

"*Rzehakina*" sp.1 (GRADSTEIN & BERGGREN)

Recommended source for illustration:
Gradstein & Berggren (1981) pl.V, figs 3-4

1981 "*Rzehakina*" sp.1 GRADSTEIN & BERGGREN p.250, pl.V, figs 3-4

DIAGNOSIS: Test free, agglutinated and small. The early whorls are coiled streptospirally, later planispirally and evolute with 2 chambers per whorl giving an elongate narrow elliptical shape to the test. The test wall is smooth and finely agglutinated.

REMARKS: Gradstein & Berggren (1981) recorded this species as occurring in higher stratigraphic levels (their "interval with *Cyclammina amplectens* of Eocene age") than *R.epigona*, which disappears in the Early-Middle Eocene in the Labrador Sea.

RANGE: Eocene (?Early - Middle) (Gradstein & Berggren, 19981)

OCCURRENCE IN THIS WORK:

<table>
<tr><td colspan="6">OFFSHORE</td></tr>
<tr><td>21/26-1</td><td></td><td>49/10-1</td><td></td><td>49/24-3</td><td></td></tr>
<tr><td>29/25-1</td><td></td><td>49/20-2</td><td></td><td>49/24-4</td><td></td></tr>
<tr><td>44/2-1</td><td></td><td>49/24-2</td><td></td><td>49/25-2</td><td>rare</td></tr>
<tr><td colspan="6">ONSHORE</td></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td></td></tr>
<tr><td colspan="2">Pegwell Bay</td><td></td><td colspan="2">Stevns Klint</td><td></td></tr>
<tr><td colspan="2">Reculver</td><td></td><td colspan="2"></td><td></td></tr>
</table>

Superfamily HORMOSINACEA Haeckel, 1894
Family HORMOSINIDAE Haeckel, 1894
Genus *Reophax* de Montfort, 1808
***Reophax pilulifer* BRADY**
Recommended source for illustration:
Gradstein & Berggren (1981) pl.II, figs 10-11

1884 *Reophax pilulifera* BRADY p.292 pl.30 figs 18-20
1981 *Reophax pilulifer* Brady: GRADSTEIN & BERGGREN p.248 pl.2 figs.10-11
1990 *Hormosina pilulifer* (Brady): CHARNOCK & JONES p.162, pl.4, fig.5, pl.15, fig.7

DIAGNOSIS: Test free, agglutinated. few (normally 3-4) subglobular to barrel-shaped chambers arranged uniserially and increasing moderately rapidly in size.

REMARKS: The only species of this genus to be observed in this study and the only one from the North Sea to be illustrated by Gradstein & Berggren (1981).

RANGE: Late Palaeocene - ?Oligocene (this study).

OCCURRENCE IN THIS WORK:

<table>
<tr><td colspan="6">OFFSHORE</td></tr>
<tr><td>21/26-1</td><td></td><td>49/10-1</td><td></td><td>49/24-3</td><td>?</td></tr>
<tr><td>29/25-1</td><td>rare</td><td>49/20-2</td><td></td><td>49/24-4</td><td></td></tr>
<tr><td>44/2-1</td><td></td><td>49/24-2</td><td></td><td>49/25-2</td><td></td></tr>
<tr><td colspan="6">ONSHORE</td></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td></td></tr>
<tr><td colspan="2">Pegwell Bay</td><td></td><td colspan="2">Stevns Klint</td><td></td></tr>
<tr><td colspan="2">Reculver</td><td></td><td colspan="2"></td><td></td></tr>
</table>

Superfamily LITUOLACEA de Blainville, 1827
Family HAPLOPHRAGMOIDIDAE Maync, 1952
Genus *Cribrostomoides* Cushman, 1910
***Cribrostomoides scitulus* (BRADY)**
Recommended source for illustration:
Gradstein & Berggren (1981) pl.VI, figs 8-9

1881 *Haplophragmium scitulum* BRADY, p.50
1981 *Cribrostomoides scitulus* (Brady): GRADSTEIN & BERGGREN p.252, pl.6, figs.8-9
1983 *Cribrostomoides scitulus* (Brady): CHARNOCK p.116, pl.4, figs.12-13
1989 *Cribrostomoides scitulus* (Brady): KING p.455, pl.9.2, figs.9-10
1990 *Labrospira scitula* (Brady): CHARNOCK & JONES p.172, pl.6, figs 9-10, pl.17, fig.6

DIAGNOSIS: Test free, moderately large, planispiral, only moderately evolute, 9-10 broad, wide and relatively low non-inflated chambers, periphery broadly rounded, sutures depressed and radial.

REMARKS: King (1989) remarks that the generic assignment is tentative as the aperture (which is characteristically multiple and areal in *Cribrostomoides*) is often rarely visible in North Sea material. The material examined in this study yielded no further information to clarify this assignment.

Charnock & Jones (1990) state that in fact the coiling shown in this species is streptospiral and therefore have reinstated the genus *Labrospira* which had previously been synonymised with *Cribrostomoides* by Loeblich & Tappan, 1964.

RANGE: Middle Eocene - Early Oligocene (King, 1989); Maastrichtian - Eocene (Gradstein & Berggren, 1981); Maastrichtian - Recent (Charnock, 1983).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Haplophragmoides* Cushman, 1910

***Haplophragmoides walteri* (GRZYBOWSKI)**

Recommended source for illustration:

Gradstein & Berggren (1981) pl. VI, figs 5-7

1898 *Trochammina walteri* GRZYBOWSKI p.290, pl.11, fig.31

1960 *Haplophragmoides walteri* (Grzybowski): GEROCH p.49, pl.5, fig.5

1981 *Haplophragmoides walteri* (Grzybowski): GRADSTEIN & BERGGREN, p.250, pl.VI, figs 5-7

1990 *Haplophragmoides walteri* (Grzybowski): CHARNOCK & JONES p.171, pl.6, figs 3-4, pl.17, fig.2

DIAGNOSIS: Test planispiral, involute and often compressed, periphery circular and non-lobate, 8-15 chambers in the final whorl increasing slowly in size, sutures radial and slightly depressed.

REMARKS: In the material recorded in this study, most specimens possess 8-10 chambers in the final whorl.

RANGE: Late Cretaceous - Eocene, common in the Early Eocene (Gradstein & Berggren, 1981). Charnock & Jones (1990) indicate that this species ranges up to the Miocene.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	mod. comm.	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily HAPLOPHRAGMIACEA Eimer & Fickert, 1899
Family AMMOSPHAERINOIDINIDAE Cushman, 1927
Genus *Praecystammina* Krasheninnikov, 1973
***Praecystammina globigerinaeformis* KRASHENINNIKOV**
Recommended source for illustration:
Gradstein & Berggren (1981) pl.IX, figs 11-15

1973 *Praecystammina globigerinaeformis* KRASHENINNIKOV p.211 pl.2 figs.1-2

1981 *Praecystammina globigerinaeformis* Krasheninnikov: GRADSTEIN & BERGGREN p.258 pl.9 figs.11-15

1989 *Cystammina* sp.*A* KING p.455 pl.9.1 figs.14-15

1990 *Cystammina pauciloculata* (Brady): CHARNOCK & JONES p.168, pl.5, fig.7, pl.16, fig.4

DIAGNOSIS: Test free, agglutinated and coiled (at least in the later stage) in "globigerine" manner generally with 3 inflated chambers in the final whorl increasing fairly rapidly in size. The coiling is streptospiral in form. The aperture is a fairly broad, slit-like opening near the base of the last chamber and is often bordered by a thin lip.

REMARKS: This is a very distinctive North Sea agglutinating species which resembles a planktonic foraminifera (*Globigerina*) in chamber arrangement although it's coiling mode is probably streptospiral rather than trochoid in the strict sense. Charnock & Jones (1990) state that *P.globigerinaeformis* is "... quite distinct from this species (i.e. *C.pauciloculata*)" although they appear to suggest that it is mainly due to a subtle difference in aperture shape.

RANGE: Palaeocene - Eocene (North Sea - Gradstein & Berggren, 1981), Late Palaeocene - Early Oligocene (North Sea - King, 1989). However, Mudge & Copestake

(1992) use the first downhole occurrence of this species (with others) to mark their Bioevent M4 of Late Palaeocene age. This event occurs within the Lista Formation and can be used to pick the top of the Balmoral Member, especially in the Outer Moray Firth.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	?
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	mod.comm.	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Recurvoides* Earland, 1934

***Recurvoides walteri* gr. (GRZYBOWSKI)**

Recommended source for illustration:

Gradstein & Berggren (1981) pl.VIII, figs 1-7

1898 *Haplophragmoides walteri* GRZYBOWSKI p.280 pl.10 fig.24

1967 *Recurvoides walteri* (Grzybowski): JURKIEWICZ p.78 pl.4 fig.14

1981 *Recurvoides* ex gr. *walteri* (Grzybowski):GRADSTEIN & BERGGREN p.253 pl.8 figs.1-7

1989 *Recurvoides* gr. *walteri* (Grzybowski): KING p.458

1990 *Recurvoides* ex gr. *turbinatus* (Brady): CHARNOCK & JONES p.173, pl.6, figs 13-15, pl.17, fig.8

DIAGNOSIS: Test free, agglutinated, fairly large, subglobular and streptospiral. Usually 5-6 chambers in the final whorl increasing moderately in size. The aperture is areal, a short oval opening near the base of the final chamber.

REMARKS: This species may be confused with *Haplophragmoides subglobosus* which is completely planispiral. Gradstein & Berggren (1981) recorded large numbers or *R.* ex gr. *walteri* from their North Sea material and indicate a high degree of variability for this species, hence their broad interpretation of this species and the assignment of "*ex gr.*" to the taxonomic structure.

RANGE: Late Cretaceous - Miocene (King, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	mod.comm.	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver		rare			

Superfamily COSCINOPHRAGMATACEA Thalmann, 1951
Family CYCLAMMINIDAE Marie, 1941
Genus *Reticulophragmium* Maync, 1955
***Reticulophragmium amplectens* (GRZYBOWSKI)**
Recommended source for illustration:
Gradstein & Berggren (1981) pl.VII, figs 13-17

1889 *Cyclammina amplectens* GRZYBOWSKI p.292 pl.12 figs.1-3
1981 *Cyclammina amplectens* Grzybowski: GRADSTEIN & BERGGREN p.253 pl.7 figs.13-17
1983 *Reticulophragmium amplectens* (Grzybowski):CHARNOCK p.124 pl.5 figs.10-11
1989 *Reticulophragmium amplectens* (Grzybowski): KING p.458 pl.9.2 figs.16-18
1990 *Cyclammina (Reticulophragmium) amplectens* Grzybowski: CHARNOCK & JONES p.176, pl.8, figs 1-5, pl.18, fig.3

DIAGNOSIS: Test free, agglutinated. A compressed planispiral evolute test with a thick central area tapering to a narrow, subacute periphery. There are numerous chambers (13-20) in the final whorl separated by slightly depressed almost straight sutures along which can sometimes be seen the internal labyrynthic structures. The aperture is a low arch near the base of the apertural face.

REMARKS: The generic assignment of this species (and of other *Reticulophragmium* species herein) follows that of Charnock (1983) and King (1989) who remove this species from *Cyclammina* on the basis of its lack of the multiple areal apertures characteristic of that genus. Charnock & Jones (1990) later reduced *Reticulophragmium* to subgeneric status.

This species is distinguishable from its close relatives by the typical inflation of the central area around the rather depressed umbilicus leading to rather trapezioid type shape when viewed aperturally. The oldest (Late Palaeocene) representative of this genus, *Reticulophragmium* sp.*A* of King, 1989 (= *R. cf. garcilassoi* of Kaminski *et al.* cited as in press by King, 1989), was not recorded from the material studied.

Charnock & Jones (1990) have also noted the apparently stratigraphically-related gradual development of alveoles in the wall structure of this species. Stratigraphically primitive individuals develop primary alveoles only, while later representatives develop secondary and tertiary alveoles (*sensu* Brönnimann, 1951). Also, more "advanced" individuals also display the alveolar structure earlier in their growth (i.e. between the 5th and 13th chambers), compared with more primitive forms (between the 10th and 17th chambers). This is probably the basis by which King (1989) recognises two subspecies of this taxon (see below).

RANGE: King (1989) restricts this taxon to the Early - Middle Eocene, NSA 4 Zone, in the North Sea although Charnock & Jones (1990) suggest that it may range higher into the Oligocene.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1	mod.comm.	**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**	?	**49/25-2**	
ONSHORE					
Wormingford Mere				**Lundsgaards Cliff**	
Pegwell Bay				**Stevns Klint**	
Reculver					

***Reticulophragmium amplectens* subsp.*A* KING**

Pl.1 Fig.A

1989 *Reticulophragmium amplectens subsp.A* KING p.458

DIAGNOSIS: Very similar to *R.amplectens s.s.*, but has fewer chambers (never more than 19) and a more acute periphery. The umbilical depression is narrower but still is relatively deep. The raised central umbilical area is also less well developed which results in the lack of the typical trapezioid shape of *R.amplectens*. It also appears to have a more "advanced" wall structure (see *R.amplectens* above).

REMARKS: This species is often confused with *R.placenta* (an Eocene - Miocene form - see below) which has slightly fewer chambers.

RANGE: King (1989) restricts this taxon to the Middle - Late Eocene i.e. stratigraphically higher than *R.amplectens s.s.*

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Reticulophragmium placenta (REUSS)

Recommended source for illustration:
Gradstein & Berggren (1981) pl.VII, figs 4-8

1851 *Nonoinina placenta* REUSS p.72, pl.5, fig.33
1868 *Haplophragmium acutidorsatum* HANTKEN p.82, pl.1, fig.1
1981 *Cyclammina placenta* (Reuss):GRADSTEIN & BERGGREN p.254 pl.VII, figs 4-8
1989 *Reticulophragmium acutidorsatum* (Hantken): KING p.458, pl.9.2, fig.15
1989 *Reticulophragmium placenta* (Reuss): KING p.458 pl.9.2, figs 20-21
1990 *Cyclammina (Cyclammina) placenta* (Reuss): CHARNOCK & JONES p.175, pl.7, figs 5-12, pl.18, fig.4

DIAGNOSIS: Test planispiral, involute, compressed, 10-16 chambers in the final whorl, periphery rounded to subacute.

REMARKS: King (1989) separates *R.acutidorsatum* on the basis of a more acute periphery, a feature that is difficult to quantify adequately in the material recorded here. Gradstein & Berggren (1981) regard the two as synonymous.

King also includes specimens referred to by Gradstein & Berggren as *Cyclammina cancellata* in his concept of *R.placenta*. *C.cancellata* was not observed in this material but has a "fatter" i.e. less compressed test shape and is believed to have evolved from

R.placenta (Gradstein & Berggren, 1981). Charnock & Jones (1990) also state the need for further investigation between these tow forms.

RANGE: Middle Eocene - Miocene (King, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1	mod.comm.	**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily SPIROPLECTAMMINACEA Cushman, 1927
Family SPIROPLECTAMMINIDAE Cushman, 1927
Genus *Spiroplectammina* Cushman, 1927
***Spiroplectammina adamsi* LALICKER**
Recommended source for illustration:
Murray *et al.* (1989) pl.10.1, figs 1-2

1935 *Spiroplectammina adamsi* LALICKER
1989 *Bolivinopsis adamsi* (Lalicker): MURRAY *et al.*, p.508, pl.10.1, fig.1

DIAGNOSIS: Test initially planispiral, becoming biserial and rapidly enlarging, a thick axial portion giving a broad rhomboidal cross section, lateral margins appear serrated with chambers having somewhat pointed edges or even a lateral flange.

REMARKS: Loeblich & Tappan (1988) state that use of the genus *Bolivinopsis* for these morphotypes should be restricted to forms older than the Cenozoic. As with most specimens of *Spiroplectammina*, the initial planispiral coil is often difficult to see on microspheric generations, or is commonly broken off altogether.

The rapidly flaring test and thick, rhomboid cross-section are characteristic for this species.

RANGE: Early Eocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**	rare	**49/25-2**	?
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Spiroplectammina carinata **(D'ORBIGNY)**
Recommended source for illustration:
Doppert & Neale (1983) pl. VI, figs 1

1846 *Bolivinopsis carinata* D'ORBIGNY

1983 *Spiroplectammina carinata* (d'Orbigny): DOPPERT & NEALE p.26, p.VI, fig.1

1990 *Spiroplectammina (Spiroplectinella) carinata* (d'Orbigny): CHARNOCK & JONES p.182, pl.21, fig.3

DIAGNOSIS: Test initially planispiral, becoming biserial and rapidly enlarging. Test compressed giving a thin rhomboidal cross section. Lateral margins appear very serrated with chambers having somewhat pointed edges or even a lateral flange.

REMARKS: *S.adamsi* is similar although the axial portion of the test in that case is much thicker.

RANGE: Eocene - Early Oligocene (Charnock & Jones, 1990).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	?
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Spiroplectammina navarroana CUSHMAN

Recommended source for illustration:
Gradstein & Berggren (1981) pl.III, figs 11-12

1932 *Spiroplectammina navarroana* CUSHMAN p.96, pl.11 fig.14
1935 *Textularia plummerae* LALIKER
1981 *Spiroplectammina navarroana* Cushman: GRADSTEIN & BERGGREN p.260, pl.3, figs 11-12
1983 *Spiroplectammina navarroana* Cushman: CHARNOCK p.130, pl.5, figs.4-5
1989 *Textularia plummerae* Lalicker: KING p.459, pl.9.2, fig.26
1990 *Spiroplectammina (Spiroplectammina) navarroana* Cushman: CHARNOCK & JONES p.181, pl.9, figs 11-12, pl.21, fig.1

DIAGNOSIS: Test free, a small, often missing initial coiled portion, followed by an elongate, biserially arranged series of 10-12 inflated chambers separated by depressed straight sutures. The test surface is moderately rough with distinct grains.

REMARKS: The initial coiled portion which allows placement of this species into the genus *Spiroplectammina* is often broken off. This has led to several records of this species being attributed to the genus *Textularia*, specifically *T.plummerae*. The type specimen of *T.plummerae* is also apparently broken at the point of the initial coil as is the type specimen of *S.navarroana* (see Gradstein & Berggren, 1981). King (1989) therefore regards the two species as synonymous giving *T.plummerae* priority. In the present author's opinion, however, if the type of *T.plummerae* is in fact a broken specimen of *Spiroplectammina*, and also given the priority of dates (see synonymy), the name *S.navarroana* should be the accepted taxon.

RANGE: Late Cretaceous - Early Eocene (King, 1989). The highest occurrence of this species, normally shortly followed by a downhole increase in numbers, is a useful Early Eocene indicator within the Horda / Mousa Formations of the Stronsay Group.

OCCURRENCE IN THIS WORK:

<table>
<tr><td colspan="6">OFFSHORE</td></tr>
<tr><td>r21/26-1</td><td></td><td>49/10-1</td><td>mod.comm.</td><td>49/24-3</td><td></td></tr>
<tr><td>29/25-1</td><td>rare</td><td>49/20-2</td><td></td><td>49/24-4</td><td>rare</td></tr>
<tr><td>44/2-1</td><td>?</td><td>49/24-2</td><td></td><td>49/25-2</td><td></td></tr>
<tr><td colspan="6">ONSHORE</td></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td></td></tr>
<tr><td colspan="2">Pegwell Bay</td><td></td><td colspan="2">Stevns Klint</td><td></td></tr>
<tr><td colspan="2">Reculver</td><td></td><td colspan="2"></td><td></td></tr>
</table>

Spiroplectammina spectabilis (GRZYBOWSKI)

Recommended source for illustration:
Gradstein & Berggren (1981) pl.IV, figs 1-5

1898 *Spiroplecta spectabilis* GRZYBOWSKI p.293 pl.12 fig.1
1967 *Spiroplectammina spectabilis* (Grzybowski): JURKIEWICZ p.88 text fig.19, pl.5, figs.12,15
1972 *Bolivinopsis spectabilis* (Grzybowski): HANZLIKOVA p.48 pl.10 fig.8
1972 *Spiroplectammina spectabilis* (Grzybowski): HILTERMANN p.43 pls.1-2
1981 *Spiroplectammina spectabilis* (Grzybowski): GRADSTEIN & BERGGREN p.260 pl.4 figs.1-5
1983 *Spiroplectammina spectabilis* (Grzybowski): CHARNOCK p.132 pl.6 figs.6,7 non pl.6 figs.8,9
1989 *Spiroplectammina spectabilis* (Grzybowski): KING p.459 pl.9.2 figs.28-29
1990 *Spiroplectammina (Spiroplectinella) spectabilis* (Grzybowski): CHARNOCK & JONES p.182, pl.9, figs 17-18, pl.21, fig.5 (not pl.9, figs 15-16)

DIAGNOSIS: Test free, agglutinated and elongate. A small planispiral coil (larger in megalospheric forms) followed by an uncoiled compressed biserial stage with a diamond shaped cross section. The chambers are wide and directed backwards on the outer margins of the uncoiled portion. The chambers increase slowly in size.

REMARKS: This species differs from its close "relative" *S.* aff. *spectabilis* in its more rhomboid cross section. *S.spectabilis s.s.* ranges from the Late Cretaceous to the Palaeocene whilst the more common post-Palaeocene forms are better referred to the "aff" form. Hiltermann (1972) discusses the taxonomy, morphology and distribution of this species in detail. Charnock (1983) indicates a recovery of nearly 1200 specimens from a single (unnamed) North Sea well. However, he differentiates between micro- and megalospheric generations and described the megalospheric form as "the biserial portion is parallel sided, laterally compressed and consists of about 16 chambers". He also indicates that the megalospheric forms outnumber the microspheric forms by 16:1. This author suggests that the forms referred to as megalospheric by Charnock are perhaps better referred to *S.* aff. *spectabilis*, a post-Palaeocene compressed form of the species (see below). Gradstein & Berggren (1981) also point out that post-Palaeocene representatives of this taxon are more compressed than older forms.

Charnock & Jones (1990) follow Charnock (1983) and Gradstein (1983) in regarding these two forms as no more than the result of an evolutionary trait within *S.spectabilis.* Their stratigraphic utility however, argues for at least some degree of taxonomic recognition which appears best served by the "aff." designation for the younger, more flattened form.

RANGE: Restricted to Palaeocene and older strata in the North Sea area (Gradstein & Berggren, 1981; King, 1989). The absolute highest occurrence of this taxon (which can be difficult to identify due to its scarcity at the top of its range) is used to partly define Bioevent M5 of Mudge & Copestake (1992). This event occurs at or near the top of the Lista Formation. A fairly rapid downhole increase in numbers of this species, just below its top, is normally recorded in many North Sea wells and this marker partly defines Bioevent M4 of Mudge & Copestake (1992). This event occurs within (but near the top of) the Lista Formation, and can mark the top of the Balmoral Member, especially in the Outer Moray Firth.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	?
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Spiroplectammina aff. *spectabilis* (*sensu* KING)

Recommended source for illustration:
Charnock & Jones (1990) pl.9, figs 15-16

1983 *Spiroplectammina spectabilis* (Grzybowski): CHARNOCK p.132, pl.6, figs.8,9 non pl.6, figs.6,7

1989 *Spiroplectammina* aff. *spectabilis* KING: p.459

1990 *Spiroplectammina (Spiroplectinella) spectabilis* (Grzybowski): CHARNOCK & JONES p.182, pl.9, figs 15-16 not 17-18, not pl.21, fig.5

DIAGNOSIS: A variant of *S.spectabilis s.s.* with a more laterally compressed test and a less rhomboid cross-section.

REMARKS: This taxon is less common than *S.spectabilis* in the material studied. Most of the forms described by Charnock (1983) would be best referred to this taxon (see above for discussion).

RANGE: Early - Middle Eocene (see King, 1989). Charnock & Jones (1990) state that the highest occurrence of this (aff.) taxon is a valuable, isochronous bioevent which occurs within the same palynomorph zone (*P.costata*) throughout the Central North Sea.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Spiroplectammina thanetana (LALICKER)
Recommended source for illustration:
Murray *et al.* (1989) pl.10.1, figs 7-9

1897 *Textularia sagittula* BURROWS & HOLLAND p.31, pl.11, fig.10
1955 *Textularia thanetana* LALICKER p.51, pl.7, fig.7
1958 *Textularia thanetana* Lalicker: HAYNES p.60, pl.15, fig.5
1989 *Spiroplectammina thanetana* (Lalicker): MURRAY *et al.*, p.510, pl.10.1, figs 7-9

DIAGNOSIS: Test elongate triangular, a small, almost indistinct initial planispire followed by an uncoiled biserial portion, rhomboid in cross section, periphery subacute.

REMARKS: *S.spectabilis s.s.* (i.e. the rhomboid form) has subparallel sides whereas *S.thanetana* is distinctly tapering though not as flaring as *S.adamsi*. *S.navarroana* has a rounded periphery.

RANGE: Late Palaeocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		common	**Stevns Klint**		
Reculver		v.common			

Superfamily TROCHAMMINACEA Schwager, 1877
Family TROCHAMMINIDAE Schwager, 1877
Genus *Trochammina* Parker & Jones, 1859
***Trochammina? volupta* (HAYNES)**
Recommended source for illustration:
Murray *et al.* (1989) pl.10.1, figs 10-12

1956 *Gyroidinoides voluptus* HAYNES p.93, pl.17, fig.4, pl.18, fig.1
?1966 *Trochammina inflata* (Montagu): HOFKER pl.77, figs 13-15
1989 *Trochammina? volupta* (Haynes): MURRAY *et al.*, p.510, pl.10.1 figs 10-12

DIAGNOSIS: Test almost planoconvex, a low trochospire, 5-7 globose chambers in the final whorl, high umbilical side. Aperture a long, low arch. Wall is apparently (though very finely) agglutinated and is normally white in colour.

REMARKS: The wall structure of this taxon is apparently agglutinated with detrital grains (Murray *et al.*, 1989) although lack of study renders the generic assignment of this taxon uncertain. It is found in sediments of normal marine, inner shelf character (Murray *et al.*, 1989).

A form illustrated as *Trochammina inflata* by Hofker (1966) appears to be similar. If it can be shown that the Danish specimens are equivalent to those recorded in the U.K., Hofker's taxon would gain priority.

RANGE: Late Palaeocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		?	**Stevns Klint**		
Reculver					

Superfamily VERNEUILINACEA Cushman, 1911
Family VERNEUILINIDAE Cushman, 1911
Genus *Gaudryina* d'Orbigny, 1839
Gaudryina hiltermanni **MEISL**
Recommended source for illustration:
Murray *et al.* (1989) pl.10.1, figs 5-6

1959 *Gaudryina hiltermanni* MEISL
1989 *Gaudryina hiltermanni* Meisl: KING p.455, pl.9.1, fig.16
1989 *Gaudryina hiltermanni* Meisl: MURRAY *et al.*, p.510, pl.10.1, figs 5-6
1990 *Gaudryina hiltermanni* Meisl: CHARNOCK & JONES p.193, pl.12, figs 13-14, pl.25, fig.4

DIAGNOSIS: Test free, relatively large, elongate, a triserial stage with a sharp edged triangular cross-section followed by an biserial stage with a more rounded cross-section.

REMARKS: Similar to *Clavulina anglica* which has a uniserial second portion. However, this latter portion is often missing in the specimens recorded in this study.

RANGE: Early Eocene (King, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily ATAXOPHRAGMIACEA Schwager, 1877
Family GLOBOTEXTULARIIDAE Cushman, 1927
Genus *Matanzia* Palmer, 1936
***Matanzia varians* (GLAESSNER)**
Recommended source for illustration:
King (1989) pl.9.2, figs 7-8

1937 *Textulariella varians* GLAESSNER
1944 *Matanzia varians* (Glaessner): TEN DAM
1989 *Matanzia varians* (Glaessner): KING p.456, pl.9.2, figs 7-8
1990 *Remesella varians* (Glaessner): CHARNOCK & JONES p.197, pl.12, figs 21-22, pl.25, fig.12

DIAGNOSIS: Test initially triserial but rapidly expanding to biserial in the final stages, cross-section almost circular, periphery gently tapering sutures slightly depressed and gently curved, chambers moderately inflated, wall relatively finely agglutinated, aperture a broad, looped slit opening at the base of the apertural face.

REMARKS: This is a fairly distinctive taxon in the material examined. Taxa referred to "*Dorothia*" sp.6 from the Eocene of an unnamed North Sea well, and *Dorothia oxycona* from the Maastrichtian of the Labrador Shelf by Gradstein & Berggren (1981) are similar but have more strongly tapering tests.

Species of *Karreriella* are normally at least triserial throughout and have a more coarsely agglutinated wall structure.

RANGE: Late Palaeocene (King, 1989). Charnock & Jones (1990) state that it's extinction occurs within, rather than at the top of the Late Palaeocene.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		rare
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily TEXTULARIACEA Ehrenberg, 1838
Genus *Karreriella* Cushman, 1933
***Karreriella conversa* (GRZYBOWSKI)**
Recommended source for illustration:
Gradstein & Berggren (1981) pl.IV, figs 11-15

1901 *Gaudryina conversa* GRZYBOWSKI
1911 *Gaudryina apicularis* CUSHMAN p.69, fig.110
1981 *Karreriella apicularis* (Cushman): GRADSTEIN & BERGGREN p.263, pl.IV, figs 11-15
1989 *Karreriella conversa* (Grzybowski): KING p.456, pl.9.1, figs 23-24
1990 *Karrerulina conversa* (Grzybowski): CHARNOCK & JONES p.195, pl.12, fig.19, pl.25, fig.10

DIAGNOSIS: Test elongate, slightly twisted, initially multiserial or triserial, becoming triserial or nearly biserial later, chambers moderately inflated, subglobular to barrel-shaped, sutures relatively indistinct, wall normally fairly coarsely agglutinated.

REMARKS: In some specimens, dark, opaque (?heavy mineral) grains are incorporated into the wall material close to the sutures. Some workers (e.g. Mears *pers. comm.*; Dyer *pers. comm.*) regard this feature as having possible stratigraphical significance, being observed (so far) from Late Palaeocene specimens only in the North Sea area.

RANGE: Late Cretaceous - Early Oligocene (King, 1989). However, according to Mudge & Copestake (1992) the stratigraphic top this species is used to partly define their Bioevent M4 of Late Palaeocene age (see Remarks above).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1	mod.comm.	**49/20-2**		**49/24-4**	rare
44/2-1	mod.comm.	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Family VALVULINIDAE Berthelin, 1880
Genus *Clavulina* d'Orbigny, 1826
***Clavulina anglica* (CUSHMAN)**
Recommended source for illustration:
Murray *et al.* (1989) pl.10.1, figs 3-4

1936 *Pseudoclavulina anglica* CUSHMAN
1983 *Pseudoclavulina anglica* Cushman: DOPPERT & NEELE pl.XIX, fig.3a-b
1989 *Clavulina anglica* (Cushman): KING p.454, pl.9.1, fig.22
1989 *Clavulina anglica* (Cushman): MURRAY *et al.*, p.508, pl.10.1, figs 3-4
1990 *Pseudoclavulina anglica* Cushman: CHARNOCK & JONES p.196, pl.12, fig.20, pl.25, fig.11

DIAGNOSIS: Elongate, large, trigonal early triserial stage followed by a uniserial portion with a circular cross section with later chambers becoming inflated and subglobular.

REMARKS: *C.cocoaensis* Cushman (Middle - Late Eocene) has a smaller and more rounded cross sectional triserial portion with a very elongate uniserial portion. The uniserial part of this species is often broken in the specimens recorded in this study and can be difficult to separate from *Gaudryina hiltermanni* which also has a triangular triserial portion.

RANGE: King (1989) indicates that this species ranges from the Late Palaeocene - Early Eocene in the North Sea and ranges up to the Middle Eocene in onshore sequences. Murray *et al.* (1989) however, only record an Early Eocene range for the onshore U.K. Doppert & Neele (1983) record this species from the latest Palaeocene - Early Eocene of the Dutch onshore.

OCCURRENCE IN THIS WORK:

<table>
<tr><th colspan="6">OFFSHORE</th></tr>
<tr><td>21/26-1</td><td></td><td>49/10-1</td><td></td><td>49/24-3</td><td></td></tr>
<tr><td>29/25-1</td><td></td><td>49/20-2</td><td></td><td>49/24-4</td><td></td></tr>
<tr><td>44/2-1</td><td></td><td>49/24-2</td><td></td><td>49/25-2</td><td>rare</td></tr>
<tr><th colspan="6">ONSHORE</th></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td></td></tr>
<tr><td colspan="2">Pegwell Bay</td><td></td><td colspan="2">Stevns Klint</td><td></td></tr>
<tr><td colspan="2">Reculver</td><td></td><td colspan="2"></td><td></td></tr>
</table>

Suborder MILIOLINA Delage & Herouard, 1896
Superfamily MILIOLACEA Ehrenberg, 1839
Family HAUERINIDAE Schwager, 1876
Genus *Quinqueloculina* d'Orbigny, 1826
***Quinqueloculina reicheli* LE CALVEZ**
Recommended source for illustration:
Murray *et al.* (1989) Pl.10.2, figs 7-9

1966 *Quinqueloculina (Scutuloris) reicheli* LE CALVEZ
1989 *Quinqueloculina reicheli* Le Calvez: MURRAY *et al.*, p.512, pl.10.2, figs 7-9

DIAGNOSIS: A *Quinqueloculina* with an oval test, rounded in cross section, smooth. The aperture is at an oblique open end of the last chamber, occasionally with a flap.

REMARKS: The oblique aperture is distinctive.

RANGE: Early Eocene - Early Oligocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

<table>
<tr><th colspan="6">OFFSHORE</th></tr>
<tr><td>21/26-1</td><td></td><td>49/10-1</td><td></td><td>49/24-3</td><td></td></tr>
<tr><td>29/25-1</td><td></td><td>49/20-2</td><td></td><td>49/24-4</td><td></td></tr>
<tr><td>44/2-1</td><td></td><td>49/24-2</td><td></td><td>49/25-2</td><td>rare</td></tr>
<tr><th colspan="6">ONSHORE</th></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td></td></tr>
<tr><td colspan="2">Pegwell Bay</td><td></td><td colspan="2">Stevns Klint</td><td></td></tr>
<tr><td colspan="2">Reculver</td><td></td><td colspan="2"></td><td></td></tr>
</table>

Suborder LAGENINA Delage & Herouard, 1896
Superfamily NODOSARIACEA Ehrenberg, 1838
Family NODOSARIIDAE Ehrenberg, 1838
Genus *Dentalina* Risso, 1826
***Dentalina glaessneri* TEN DAM**
Recommended source for illustration:
Haynes (1958) Pl. 16, fig.3

1897 *Dentalina communis* BURROWS & HOLLAND p.35, pl.2, figs 7-9
1944 *Dentalina glaessneri* TEN DAM p.92, pl.2, fig.11
1958 *Dentalina glaessneri* Ten Dam: HAYNES p.66, pl.16, fig.3

DIAGNOSIS: Test elongate, gently curving, approximately 6 elongate "barrel shaped" chambers, sutures oblique and depressed, surface covered with fine longitudinal costae, aperture terminal, usually positioned closest to the more concave margin of the curved test.

REMARKS: This species resembles *Nodosaria latejugata* in the possession of depressed sutures and longitudinal costae. It is, however, distinctly curved and possesses a non-central aperture (i.e. is best referred to *Dentalina*).

RANGE: Palaeocene (Haynes, 1958).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	

ONSHORE			
Wormingford Mere		**Lundsgaards Cliff**	rare
Pegwell Bay	rare	**Stevns Klint**	
Reculver			

Genus *Nodosaria* Lamark, 1812
***Nodosaria latejugata* GUEMBEL**
Recommended source for illustration:
King (1989) Pl. 9.4, fig.3

1868 *Nodosaria latejugata* GUEMBEL
1989 *Nodosaria latejugata* Guembel: KING p.464, pl.9.4, fig.3

DIAGNOSIS: Test generally large with "barrel-shaped" chambers slightly longer than broad. Numerous thin but "high" longitudinal ribs present which cross the depressed sutures.

REMARKS: A distinctive large species. *Nodosaria minor* Hantken has only slightly depressed sutures and King (1989) regards the two taxa to be dimorphic forms of the same species.

RANGE: Late Palaeocene - Late Eocene (King, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		?
Pegwell Bay			**Stevns Klint**		
Reculver		rare			

Nodosaria spinescens **(REUSS)**
Recommended source for illustration:
Doppert & Neele (1983) Pl. VII, figs 2-3

1851a *Dentalina spinescens* REUSS
1983 *Nodosaria spinescens* (Reuss): DOPPERT & NEELE p.28, pl.VII, figs.2-3

DIAGNOSIS: Test with "barrel-shaped" chambers and depressed sutures. Chamber surface is smooth apart from a band of 10-12 short blunt retrograde spines which occur posterior of the equatorial line of each chamber.

REMARKS: Some specimens have the band of spines occurring around the equatorial line. These have been logged as *Nodosaria ?spinescens* on charts.

RANGE: Oligocene (Doppert & Neele, 1983)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	mod.comm.
ONSHORE					
Wormingford Mere		**Lundsgaards Cliff**			
Pegwell Bay		**Stevns Klint**			
Reculver					

Family VAGINULINIDAE Reuss, 1860
Genus *Lenticulina* Lamarck, 1804
***Lenticulina klagshamnensis* (BROTZEN)**
Recommended source for illustration:
Hofker (1966) pl. 40, figs 12-13

1948	*Robulus klagshamnensis* BROTZEN p.41, pl.7, figs 1-2
1966	*Robulus klagshamnensis* Brotzen: HOFKER p.219, pl.40, figs 12-13

DIAGNOSIS: Test free, planispiral, involute, compressed and fairly strongly keeled. About 8-9 chambers in the final whorl. Sutures, raised, distinct and recurved. Central umbilical area without a distinct boss.

REMARKS: *L.turbinatus* has more strongly recurved sutures..

RANGE: Palaeocene. Also recorded from the Vincetown and Midway Formations of America (Hofker, 1966).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere		**Lundsgaards Cliff**	rare		
Pegwell Bay		**Stevns Klint**			
Reculver					

Lenticulina platypleura FRANKE

Recommended source for illustration:
King (1989) Pl. 9.3, fig.20

1911 *Lenticulina multiformis* FRANKE
1989 *Lenticulina platypleura* (Jones): KING p.463 pl.9.3 fig.20

DIAGNOSIS: Test free, compressed, around 8 chambers in the final whorl, planispiral involute varying from fully coiled to uncoiled, periphery acute, sutures marked with raised ribs.

REMARKS: The ornamentation is quite variable in this species, particularly in the strength of the sutural ribs. In was recorded as common in the Pegwell Marls by Haynes (1958c).

RANGE: Late Palaeocene (King, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	?	**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**	?	**49/25-2**	rare
ONSHORE					
Wormingford Mere		**Lundsgaards Cliff**			
Pegwell Bay		**Stevns Klint**			
Reculver					

Lenticulina turbinatus PLUMMER

Recommended source for illustration:
Hofker (1966) pl. 68, figs 43-44

1926 *Cristellaria turbinata* PLUMMER p.93, pl.7, fig.4
1951 *Robulus turbinatus* (Plummer): CUSHMAN p.14, pl.4, figs 6-9
1966 *Robulus turbinatus* (Plummer): HOFKER p.308, pl.68, figs 43-44

DIAGNOSIS: Test rather small, compressed with a fairly strong keel. About 7-9 strongly recurved chambers in the final, involute, whorl. Sutures raised, distinct and highly "turbinate" (Hofker, 1966 p.308) i.e. recurved.

REMARKS: *L.klagshamnensis* is similar although the sutures are not as recurved

RANGE: Palaeocene(Hofker, 1966).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		mod. comm.
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Saracenaria* Defrance, 1824

***Saracenaria hartingi* TEN DAM**

Recommended source for illustration:

Hofker (1966) pl. 77, fig. 20

1944 *Astacolus hartingi* TEN DAM

1966 *Astacolus hartingi* Ten Dam: HOFKER pl.77, fig.20

DIAGNOSIS: Test planispiral, a rapidly expanding coil, both in terms of chamber height and breadth. About 5-6 chambers in the final whorl. Sutures mainly flush, becoming slightly depressed in the last few chambers and recurved. Rather bulbous chamber flaps on the final chamber overhang the central area. Apertural face broadly convex. Aperture radiate, terminal.

REMARKS: This species is placed in the genus *Saracenaria* as it does not uncoil as completely as in typical *Astacolus* spp.

RANGE: ?Palaeocene (Hofker, 1966).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		rare
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Astacolus* de Montfort, 1808

***Astacolus* ?sp.nov.**

Pl.1 Fig.B

DIAGNOSIS: Test large, initially planispiral becoming rapidly uncoiled, mainly elongate, occasionally less uncoiled, slightly compressed with a well rounded periphery, sutures only moderately distinct, flush to slightly depressed, very oblique in later part of uncoiled portion, aperture terminal and radiate, wall smooth and unornamented.

REMARKS: This species was recorded in abundance from a single sample (PB11) in the Pegwell bay section. It may have some similarities to *Marginulina* cf. *M.dorsata* Cushman as illustrated by Haynes, 1958b, from Horizon P16 of the Pegwell Marls which corresponds approximately to the level of the PB11 sample herein. It also may be referable to *A.* "*crepidula*" of various authors. Rarer occurrences of this taxon have also been recorded from Denmark and offshore (see below).

RANGE: Late Palaeocene (this study).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		rare
Pegwell Bay	common		**Stevns Klint**		
Reculver					

Genus *Vaginulinopsis* Silvestri, 1904

Vaginulinopsis decorata **(REUSS)**

Recommended source for illustration:
King (1989) Pl.9.4, fig. 11

1855 *Cristellaria decorata* REUSS
1989 *Vaginulinopsis decorata* (Reuss): KING p.466 pl.9.4 fig.11

DIAGNOSIS: Test free, relatively large, uncoiled planispiral with small initial planispiral coil, periphery subrounded to keeled, chambers short and wide, numbering about 6-8 in the uncoiled portion, ornament variable but predominantly composed of sutural tubercles which may be somewhat elongated longitudinally into short ribs which tend to become more continuous near the periphery.

REMARKS: King (1989) remarks that this highly variable species may, with further study, reveal useful chronological subspecies as the ornamentation style tends to change from predominantly smooth sutural ribs in the Early Eocene (*V.decorata subsp.A* - see below) to more longitudinally elongated tubercles and without sutural ribs by the Middle - Late Eocene (this species). King also mentions an intermediate form occurring in the Early - Middle Eocene with thick, tuberculate sutural ribs but does not distinguish it as a distinct subspecies.

RANGE: Middle - Late Eocene (King, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Vaginulinopsis decorata subsp.A **KING**

Recommended source for illustration:
King (1989) Pl.9.4, fig.12

1989 *Vaginulinopsis decorata subsp.A*: KING, p.466, pl.9.4 fig.12

DIAGNOSIS: Similar to *V.decorata* but with smooth sutural ribs. Irregular tuberculation may be present on the initial coil.

REMARKS: King (1989) regards this subspecies as the earliest in a morphological and chronological gradation, where surface ornament changes from predominantly sutural to predominantly longitudinal in aspect.

RANGE: Early - ?Middle Eocene (King, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**		**49/25-2**	rare

ONSHORE			
Wormingford Mere		**Lundsgaards Cliff**	
Pegwell Bay		**Stevns Klint**	
Reculver			

Vaginulinopsis aff. *decorata* KING

Recommended source for illustration:
King (1989) Pl.9.4, fig.14

1989 *Vaginulinopsis* sp.*B*: KING, p.466, pl.9.4 fig.14

DIAGNOSIS: Test fairly large and compressed. Small initial coil followed by an uncoiled portion of c.8-10 short and wide chambers. Surface ornamentation consists of many discontinuous longitudinal ribs or longitudinally elongated tubercles which tend to become more prominent towards the periphery though tending to fade on the later chambers.

REMARKS: The predominantly longitudinal nature of the ornamentation, together with the more compressed nature of the test, serve to distinguish this form from others of the *V.decorata* plexus.

RANGE: King (1989) regards this form as a widespread species in the lower part of the Early Oligocene.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		49/10-1		49/24-3	
29/25-1		49/20-2		49/24-4	rare
44/2-1	?	49/24-2	rare	49/25-2	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Citharina* d'Orbigny, 1839

Citharina plummoides **(PLUMMER)**

Recommended source for illustration:

Hofker (1966) pl. 80, fig. 94

1926 *Vaginulina plummoides* PLUMMER p.120, pl.5, fig.4
1948 *Citharina plummoides* (Plummer): BROTZEN p.45, pl.5, figs 4-5
1966 *Citharina plummoides* (Plummer): HOFKER, pl.80, fig.94

DIAGNOSIS: Test highly flattened, blade-like with numerous narrow chambers. The change in rate of chamber addition in the initial part results in a concave, hook-shaped feature. The surface is covered in very fine longitudinal striations.

REMARKS: This forms has been regarded as typical within Palaeocene sediments of southern Scandinavia (Brotzen , 1948)

RANGE: Latest Early - Late Palaeocene (Brotzen, 1948).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		49/10-1		49/24-3	
29/25-1		49/20-2		49/24-4	
44/2-1		49/24-2		49/25-2	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**	rare	
Pegwell Bay			**Stevns Klint**		
Reculver					

Family LAGENIDAE Reuss, 1862

Genus *Lagena* Walker & Jacob, 1798

Lagena geometrica REUSS

Recommended source for illustration:

Hofker (1966) pl. 80, figs 97, 100

1845 *Lagena geometrica* REUSS

1966 *Lagena geometrica* Reuss: HOFKER, pl.80, figs 97, 100

DIAGNOSIS: Test small, unilocular, almost spherical. Surface strongly reticulate and fairly spinose. Aperture produced on a short neck.

REMARKS: The reticulation is distinctive

RANGE: ?Palaeocene (Hofker, 1966).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		rare
Pegwell Bay			**Stevns Klint**		
Reculver					

Family POLYMORPHINIDAE d'Orbigny, 1839

Genus *Guttulina* d'Orbigny, 1839

Guttulina problema d'ORBIGNY

Recommended source for illustration:

Murray *et al.* (1989) fig.10.13i-k

1826 *Guttulina problema* d'ORBIGNY p.26 no.14

1948 *Guttulina problema* d'Orbigny: BROTZEN p.19, pl.2, figs 1-6

1948 *Guttulina communis* (Plummer): BROTZEN p.49

1958 *Guttulina problema* d'Orbigny: HAYNES p.5, pl.3, fig.5

1989 *Guttulina problema* d'Orbigny: MURRAY *et al.*, p.529, fig.10.13i-k

DIAGNOSIS: Test somewhat "tear-drop" shaped, subtriangular in cross-section arranged in a quinqueloculine series, increasing in size very rapidly, sutures depressed, aperture radiate.

REMARKS: The "tear-drop" shape is characteristic.

RANGE: Late Palaeocene - Late Eocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		rare	**Stevns Klint**		
Reculver		mod.comm.			

Genus *Globulina* d'Orbigny, 1839

***Globulina ampulla* (JONES)**

Recommended source for illustration:

Murray *et al.* (1989) fig.10.13c-e

1852 *Polymorphina ampulla* JONES p.267, pl.16, fig.14

1958 *Globulina ampulla* (Jones): HAYNES p.9, pl.4, fig.1

1989 *Globulina ampulla* (Jones): MURRAY *et al.*, p.529, fig.10.13c-e

DIAGNOSIS: Test a pointed oval, subcircular - subtriangular in cross-section, chambers added in planes 144^{o} apart, sutures slightly depressed, aperture radiate.

REMARKS:

RANGE: Late Palaeocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		rare	**Stevns Klint**		
Reculver		mod. comm.			

Suborder ROBERTININA Loeblich & Tappan, 1984
Superfamily CERATOBULIMINACEA Cushman, 1927
Family CERATOBULIMINIDAE Cushman, 1927
Genus *Ceratobulimina* Toula, 1915
***Ceratobulimina contraria* (REUSS)**
Recommended source for illustration:
Doppert & Neele (1983) pl.III, fig.1

1851b *Allomorphina contraria* REUSS
1958 *Ceratobulimina contraria* (Reuss): BATJES pl.X fig.4
1983 *Ceratobulimina contraria* (Reuss): DOPPERT & NEELE pl.III fig.1

DIAGNOSIS: Test medium to large, broadly biconvex to almost subglobular, a low trochospire with 6-7 rapidly enlarging chambers in the final whorl. 1-2 initial whorls visible on the spiral side. Chambers wide and high, triangular in umbilical view, moderately inflated to give a lobate, well rounded periphery. Sutures depressed, surface smooth. The aperture is a long slit located in a broad groove running from the umbilicus up into the apertural face.

REMARKS: This distinctive species is characteristic of the Oligocene - Early Miocene of the North Sea area.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Family EPISTOMINIDAE Wedekind, 1937

Genus *Hoeglundina* Brotzen, 1948

***Hoeglundina elegans* (d'ORBIGNY)**

Recommended source for illustration:

Van Moorkhoven *et al.* (1986) pl.29

1826 *Rotalia (Turbinulina) elegans* d'ORBIGNY p.276

1948 *Hoeglundina elegans* (d'Orbigny): BROTZEN p.92

1983 *Hoeglundina elegans* (d'Orbigny): DOPPERT & NEELE p.22, pl.IV, fig.3a-c

1986 *Hoeglundina elegans* (d'Orbigny): van MORKHOVEN *et al.*, p.97, pl.29

DIAGNOSIS: Test trochospiral, equally to unequally biconvex, acute periphery, 6-7 chambers in final whorl - subquadrate on spiral side, triangular on umbilical side, wall smooth, essentially imperforate, often shiny, sutures flush, distinct, recurved on spiral side, radial on umbilical side. Aperture small and often not seen, supplementary aperture a long, low slit, close to the periphery on the umbilical side. They are closed on earlier chambers and are normally only visible as scars along the periphery.

REMARKS: The smooth, shiny wall and supplementary apertural scars easily distinguish this species. This species has been found from inner neritic to abyssal depths throughout its geological range, although is predominantly a slope dweller (c.300m-2000m) in modern assemblages (van Morkhoven *et al.*, 1986).

RANGE: Late Eocene - Recent (van Morkhoven *et al.*, 1986)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	?
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Suborder GLOBIGERININA Delage & Herouard, 1896
Superfamily HETEROHELICACEA Cushman, 1927
Family GUEMBELITRIIDAE Montanaro Gallitelli, 1957
Genus *Guembelitria* Cushman, 1933
***Guembelitria triseriata* (TERQUEM)**
Recommended source for illustration:
Murray *et al.* (1989) pl.10.11, figs 5-6

1979 *Guembelitria columbiana* Howe: CRITTENDEN p.114 pl.1 fig.E
1989 *Guembelitria triseriata* (Terquem): MURRAY *et al.* p.532, pl.10.11 figs.5-6

DIAGNOSIS: Test triserial, elongate, with globular chambers increasing slowly in size. Surface smooth, sutures depressed. Aperture an interiomarginal arch.

REMARKS: Recorded onshore from the Bracklesham Group (Early Eocene) of Sussex (Murray *et al.*, 1989). The specimen referred to as *G.columbiana* Howe by Crittenden (1975) appears broadly similar to this form.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**	rare	**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		mod. comm.
Reculver					

Family HETEROHELICIDAE Cushman, 1927
Genus *Heterohelix* Ehrenberg, 1843
***Heterohelix* spp.**
Recommended source for illustration:
Caron (1985) fig. 24.5-13

DIAGNOSIS: Test usually small, tapering, initially a minute planispiral coil followed by biserial chambers, or biserial throughout, chambers subglobular to globular, aperture interiomarginal and symmetrical, usually a low slit.

REMARKS: The monospecific genus *Pseudotextularia* (*P.elegans*) differs by having very wide chambers relative to chamber thickness.

Species of this genus were not differentiated in the material studied as the genus does not cross the Cretaceous - Tertiary boundary and therefore lies outwith the purpose of this project. However, numerous representatives were recovered in the offshore borehole samples studied and provide a useful guide fossil to differentiate Late Cretaceous from Early Palaeocene (Danian) chalk facies in the offshore realm.

The Tertiary genus *Chiloguembelina* is very similar but has an asymmetrical aperture which often displays modification by internal plates (Loeblich & Tappan, 1988).

RANGE: Late Albian - Maastrichtian (Caron, 1985). A useful indicator for the downhole penetration of the Cretaceous in offshore stratigraphy.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	abundant
29/25-1	mod. comm.	**49/20-2**		**49/24-4**	rare
44/2-1	abundant	**49/24-2**		**49/25-2**	abundant
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		common
Reculver					

Genus *Pseudotextularia* Rzehak, 1891
***Pseudotextularia elegans* (RZEHAK)**
Recommended source for illustration:
Caron (1985) figs 24.20-21

1891 *Cuneolina elegans* RZEHAK p.4
1895 *Pseudotextularia varians* RZEHAK pl.7 figs.1a-b
1985 *Pseudotextularia elegans* (Rzehak): CARON, p.65, figs 24.20-21

DIAGNOSIS: Test biserial, c.6-8 pairs of subglobular chambers increasing rapidly in size at first with rate of size increase slowing towards the final chambers. Chambers low but wide and deep with depth almost as large as test width. Surface covered in fine, parallel longitudinal costae. Sutures depressed. Aperture a low broad interiomarginal slit.

REMARKS: This is a very distinctive Late Cretaceous planktonic species with a worldwide range from mid Campanian - late Maastrichtian. However, in the North Sea it can be a useful index taxon for latest Maastrichtian sediments (King *et al.*, 1989) and thus can provide an indication to the penetration of the top of the Tor Formation. Its presence can also provide evidence for the presence or absence of an unconformity at the Cretaceous - Tertiary boundary.

RANGE: Mid Campanian - latest Maastrichtian, *G.ventricosa* - *A.mayaroensis* Zones (Caron, 1985) although tends to be restricted to the latest Maastrichtian in the North Sea area (King *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	?	**49/10-1**		**49/24-3**	rare
29/25-1	mod. comm.	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Racemiguembelina* Montanaro Gallitelli, 1957

Racemiguembelina fructicosa **(EGGER)**

Recommended source for illustration:
Caron (1985) figs 24.22-23

1895 *Pseudotextularia varians* RZEHAK p.217, pl.7, figs.2-3 not 1a-b
1899 *Guembelina fructicosa* EGGER p.36, pl.14, figs.8-9 not figs.24-26
1985 *Racemiguembelina fructicosa* (Egger): CARON, p.67 figs.24.22-23

DIAGNOSIS: Test conical in shape, biserial at first, soon becoming multiserial with the development of supplementary chambers. Chambers are relatively small and globular with coarse costae. Apertures are low arches, each opening into the central area and protected by ponticuli.

REMARKS: This is a distinctive Late Cretaceous planktonic species with has a short worldwide range (mid - late Maastrichtian, *G.gansseri - A.mayaroensis* Zones) making it an extremely useful species in biostratigraphy. Like *P.elegans* (above), it is a useful North Sea index taxon for the penetration of the Maastrichtian Tor Formation and can aid in the determination of the presence or absence of an unconformity at the Cretaceous - Tertiary boundary.

RANGE: Mid - late Maastrichtian, *G.gansseri - A.mayaroensis* Zones (Caron, 1985).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Family CHILOGUEMBELINIDAE Reiss, 1963
Genus *Chiloguembelina* Loeblich & Tappan, 1956
***Chiloguembelina cubensis* (PALMER)**

Recommended source for illustration:
Jenkins (1985) fig. 6.13

1979 *Chiloguembelina cubensis* (Palmer): CRITTENDEN p.114 pl.1 fig.G
1979 *Chiloguembelina victoriana* Beckmann: CRITTENDEN p.114, pl.1 fig.F
1979 *Chiloguembelina crinita* (Glaessner): CRITTENDEN p.113 pl.1 fig.H
1979 *Chiloguembelina waiparaensis* Jenkins: CRITTENDEN p.114 pl.1 fig.K
1979 *Chiloguembelina wilcoxensis* Cushman & Ponton: CRITTENDEN p.114 pl.1 fig.L
1979 *Chiloguembelina martini* (Pijpers): CRITTENDEN p.114 pl.1 fig.M
1985 *Chiloguembelina cubensis* (Palmer): TOUMARKINE & LUTERBACHER (in Bolli, Saunders & Perch-Nielsen eds.) see fig.5-6

1985 *Chiloguembelina cubensis* (Palmer): JENKINS (in Bolli, Saunders & Perch-Nielsen eds.) p.274 fig.6.13

DIAGNOSIS: Test small, elongate and biserial, with c.8-10 pairs of chambers increasing slowly in size, aperture interiomarginal and asymmetrical.

REMARKS: This species appears to be referable to *C.cubensis* which is the earliest representative of this genus to appear in the stratigraphic record (Middle Eocene). It is the only species of this genus to be included in a major compilation work on worldwide planktonic foraminifera (Jenkins *in* Bolli, Saunders & Perch-Nielsen eds., 1985). The several species illustrated by Crittenden (1979) from the 49/24-2 well in the North Sea are all considered to be referable to this taxon as their morphological differences are apparently superficial.

RANGE: Middle Eocene - earliest Oligocene (Jenkins, 1985 and Toumarkine & Luterbacher, 1985 both *in* Bolli, Saunders & Perch-Nielsen eds., 1985).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	mod. comm.	**49/10-1**		**49/24-3**	mod. comm.
29/25-1	rare	**49/20-2**	rare	**49/24-4**	
44/2-1	rare	**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay		rare	**Stevns Klint**		rare
Reculver					

Superfamily PLANOMALINACEA Bolli, Loeblich & Tappan, 1957
Family GLOBIGERINELLOIDIDAE Longoria, 1974
Genus *Globigerinelloides* Cushman & Ten Dam, 1948
Globigerinelloides praerihillensis **PESSAGNO**
Recommended source for illustration:
Caron (1985) figs 29.14-15

1967 *Globigerinelloides praerihillensis* PESSAGNO pl.90, figs 1-2
1985 *Globigerinelloides praerihillensis* Pessagno: CARON p.47, figs 29.14-15

DIAGNOSIS: Test relatively small, planispiral, mainly involute, comprising 5-7 subglobular inflated chambers in the final whorl, increasing only moderately rapidly in size, aperture a low interiomarginal slit.

REMARKS: All specimens of *Globigerinelloides* recorded in the material studied were referred to this (essentially Maastrichtian) species. No further differentiation was attempted (e.g. into *G.ultramicra* (Subbotina) which has 7-9 chambers) as the genus, which does not cross the Cretaceous - Tertiary boundary, does not fall within the scope of this project. However, numerous representatives of the genus were recovered in the offshore borehole samples studied and (like *Heterohelix* spp.) provides a useful guide fossil to differentiate Late Cretaceous from Early Palaeocene (Danian) chalk facies in the offshore realm.

RANGE: Late Campanian - Maastrichtian (Caron, 1985). A good indicator for the downhole penetration of the Cretaceous in offshore stratigraphy.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	?	**49/10-1**		**49/24-3**	rare
29/25-1	rare	**49/20-2**		**49/24-4**	rare
44/2-1	abundant	**49/24-2**		**49/25-2**	common
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		mod.comm.
Reculver					

Family HEDBERGELLIDAE Loeblich & Tappan, 1961

Genus *Hedbergella* Brönnimann & Brown, 1958

***Hedbergella holmdelensis* OLSSON**

Recommended source for illustration:
Caron (1985) fig. 25.10-11

1964 *Hedbergella holmdelensis* OLSSON, p.160, pl.1, fig.2
1985 *Hedbergella holmdelensis* Olsson: CARON, p.59, fig.25.10-11

DIAGNOSIS: Test medium to large, a low, broad trochospire, 4-5 subglobular chambers in the final whorl increasing relatively slowly in size, umbilicus small but open, aperture a low extraumbilical opening, surface smooth and finely perforate.

REMARKS: All specimens of *Hedbergella* recorded in the material studied were referred to this species, which is the only representative of this genus recorded in Campanian - Maastrichtian age strata by Caron (1985 p.36). The genus, does not cross the Cretaceous - Tertiary boundary and therefore does not fall within the scope of this project for further study.

The genus as a whole can resemble some Early Tertiary globorotaliids and so cannot be used with such certainty to differentiate between the Late Cretaceous and Early Palaeocene (Danian) components of the Chalk Group facies in the offshore realm.

RANGE: Coniacian - Maastrichtian (Caron, 1985).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	mod. comm.	**49/20-2**		**49/24-4**	
44/2-1	mod. comm.	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		mod. comm.
Reculver					

Superfamily GLOBOTRUNCANACEA Brotzen, 1942
Family GLOBOTRUNCANIDAE Brotzen, 1942
Genus *Globotruncana* Cushman, 1927
***Globotruncana linneiana* (d'ORBIGNY)**
Recommended source for illustration:
Caron (1985) fig. 20.5-6

1839 *Rosalina linneiana* d'ORBIGNY p.101 pl.15 figs.10-12
1956 *Globotruncana linneiana* (d'Orbigny):BRONNIMANN & BROWN p.542 pl.20 figs.13-15
1985 *Globotruncana linneiana* (d'Orbigny): CARON p.50 figs.20,5-6
1989 *Globotruncana linneiana* (d'Orbigny): HART *et al.* p.342 pl.7.14 figs.11-12

DIAGNOSIS: Test a circular low trochospire with both sides almost equally flat. Peripheral margins distinctly truncated with two separate widely spaced keels giving an overall box-like shape in side view. Sutures curved and raised on the spiral side, radial to slightly curved on the umbilical side. Aperture umbilical and covered by a tegillum in well preserved specimens.

REMARKS: This is a fairly distinctive species characterised by its "boxy" shape in the Cretaceous part of North Sea Chalk Group sequences. It is similar to *Globotruncana bulloides* Vogler, which has somewhat more inflated chambers. It is also easily confused with *Marginotruncana pseudolinneiana* Pessagno, an older Turonian - Santonian homeomorph from which it differs in the fully umbilical nature of its aperture (as opposed to umbilical - extraumbilical in *Marginotruncana* spp.), however, this distinction is difficult to make given the degree of preservation encountered in most NW European successions.

RANGE: Worldwide: Santonian - "mid" Maastrichtian (*D.asymmetrica* - basal *G.gansseri* Zones), Caron (1985). In the British succession it is relatively rare and is not found above the Campanian (Hart *et al.*, 1989). In the author's experience *G.linneiana* is a fairly reliable guide fossil for the Campanian of offshore Chalk Group sequences although King *et al.* (1989) record its range as no higher than the early Campanian. In the Northern North Sea (Shetland Group facies) it is recorded as ranging no younger than the early Santonian by King *et al.* (1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Globotruncanella* Reiss, 1957

***Globotruncanella havanensis* (VOORWIJK)**

Recommended source for illustration:

Caron (1985) fig. 21.3-4

1937 *Globotruncana havanensis* VOORWIJK p.195 pl.1 figs.25-26,29

1985 *Globotruncanella havanensis* (Voorwijk): CARON p.51 figs.21.3-4

1989 *Globotruncanella havanensis* (Voorwijk): HART *et al.*, p.344 pl.7.15 figs.1-2

DIAGNOSIS: Test a fairly low plano- almost concavo- convex trochospire. 4-5 subquadrate chambers increasing fairly slowly in size. Periphery lobate and acute to subacute with an imperforate band or aligned pustules instead of a true keel. Sutures depressed and radial to slightly curved on the umbilical side, strongly curved on the spiral side. Aperture a long high umbilical to extraumbilical arch which may be covered by a tegilla.

REMARKS: This species is fairly distinctive. *G.havanensis* possibly evolved from "whiteinellid" stock (Hart *et al.*, 1989) and in turn led to *G.citae* (Bolli) according to Caron (1985). Hart *et al.* (1989) however, regard *G.citae* as a synonym of *G.havanensis.* If Caron's reasoning is followed, *G.citae* led to *Abathomphalus mayaroensis* via *A.intermedius.*

RANGE: Worldwide: Late Campanian - Late Maastrichtian (*G.calcarata - A.mayaroensis* Zones), Caron (1985). In the British succession, Hart *et al.* (1989) restrict this species to the Maastrichtian.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Abathomphalus* Bolli, Loeblich & Tappan, 1957

***Abathomphalus mayaroensis* (BOLLI)**

Recommended source for illustration:

Caron (1985) fig. 21.7-9

1951 *Globotruncana mayaroensis* BOLLI p.190 pl.35 figs.10-12

1985 *Abathomphalus mayaroensis* (Bolli): CARON p.42 figs.21.7-9

1989 *Abathomphalus mayaroensis* (Bolli): HART *et al.* p.322 pl.7.4 figs.1-3

DIAGNOSIS: Test a low weakly concavo-convex trochospire with a subcircular outline. Generally 5-6 chambers in the final whorl increasing relatively slowly in size. periphery slightly lobate and truncated with a relatively widespaced double keel. The width of

separation of the keels varies with maximum separation occurring at the midpoints of the chambers. The keels are composed of short, radially oriented costae. Sutures radial and depressed on umbilical side, raised, crescentic and slightly beaded on the spiral side. Umbilicus shallow with an extraumbilical aperture, often covered by a tegilla.

REMARKS: Surface characteristics (beaded sutures and keels composed of costae) easily distinguishes this species. Its ancestor, *A.intermedius*, possesses only one keel. It can be differentiated from species of *Globotruncana* by the presence of radial sutures on the umbilical side and by the extraumbilical nature of the aperture.

RANGE: *A.mayaroensis* is a very short-ranging species, restricted to the latest Maastrichtian (*A.mayaroensis* Zone), Caron (1985). It is fairly well known throughout offshore North Sea sequences and its presence or absence can be very useful in establishing the conformable or unconformable nature of the Cretaceous - Tertiary boundary.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**	rare	
Reculver					

Family RUGOGLOBIGERINIDAE Subbotina, 1959

Genus *Archaeoglobigerina* Pessagno, 1967

***Archaeoglobigerina cretacea* (d'ORBIGNY)**

Recommended source for illustration:

Caron (1985) fig.16.5-6

1840 *Globigerina cretacea* d'ORBIGNY p.34, pl.3, figs 12-14

1985 *Archaeoglobigerina cretacea* (d'Orbigny): CARON p.43, fig.16.1-2

1989 *Archaeoglobigerina cretacea* (d'Orbigny): HART *et al.* p.322, pl.7.4, figs 4-5

DIAGNOSIS: Test a low trochospiral coil of 2½-3 whorls with 6 chambers in the final whorl. The chambers are subglobular with 2 weakly developed faint keels bordering an imperforate peripheral band leading to a somewhat truncated periphery. Sutures are radial and depressed, umbilicus broad, often covered by a tegilla.

REMARKS: This species was only recorded in the Wormingford Mere borehole samples and are therefore considered reworked in this section.

RANGE: Turonian - Early Maastrichtian (Caron, 1985).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Rugoglobigerina* Brönnimann, 1952
***Rugoglobigerina rugosa* (PLUMMER)**
Recommended source for illustration:
Caron (1985) fig. 34.9-10

1926 *Globigerina rugosa* PLUMMER p.38, pl.2, fig.10a-d
1985 *Rugoglobigerina rugosa* (Plummer): CARON p.72, fig.34.9-10
1989 *Rugoglobigerina rugosa* (Plummer): HART *et al.* p.360, pl.7.23, figs 7-9

DIAGNOSIS: Test a low trochospire of 2½-3 whorls with 4½-5 rapidly expanding, subglobular chambers in the final whorl. Sutures depressed and radial. Chamber surfaces ornamented with a meridional pattern of discontinuous ridges or costae. Aperture umbilical to extraumbilical, a relatively large opening

REMARKS: This distinctive species shows a great deal of variability which has resulted in a complex taxonomic history according to Hart *et al.* (1989). Caron (1985) has thus recognised 4 additional species (*R.hexacamerata* Brönnimann, *R.macrocephala* Brönnimann, *R.reicheli* Brönnimann and *R.scotti* (Brönnimann)) which are broadly restricted to the Middle - Late Maastrichtian interval. These 4 species are distinguished from *R.rugosa* based on differences in number of chambers per final whorl and the relative rapidity of their expansion.

The occurrence of this species in some samples from the Wormingford Mere borehole is probably due to reworking.

RANGE: Campanian - Maastrichtian (Caron, 1985).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	?	**49/20-2**		**49/24-4**	
44/2-1	common	**49/24-2**		**49/25-2**	

ONSHORE			
Wormingford Mere	mod.comm.	**Lundsgaards Cliff**	
Pegwell Bay		**Stevns Klint**	?
Reculver			

Superfamily GLOBOROTALIACEA Cushman, 1927

Family EOGLOBIGERINIDAE Blow, 1979

Genus *Eoglobigerina* Morozova, 1959

***Eoglobigerina edita* "s.l." (SUBBOTINA)**

Recommended source for illustration:

Blow (1979) pl.61, figs 2-3; pl.66, fig.1; pl.69, fig.6; pl.72, figs 6,8; pl.79, fig.3

1953 *Globigerina edita* SUBBOTINA p.54 pl.2, fig.1a-c

1979 *Eoglobigerina edita* (Subbotina): BLOW p.1210, pl.61, figs 2-3; pl.66, fig.1; pl.69, fig.6; pl.72, figs 6,8; pl.79, fig.3

DIAGNOSIS: Test small, a medium trochospire with a distinct turret-like early trochospire, 5 slowly enlarging globular chambers in the final whorl, umbilicus small, aperture a low extraumbilical asymmetrical arch.

REMARKS: *E.trivialis* "s.l." also has a high trochospire but only has 4 chambers in the final whorl. The separation of the subspecies *E.e.edita* and *E.e.praeedita* (the latter supposedly with a higher trochospire and a more closed umbilicus) could not be justified with the material studied. Hence the "s.l." designation.

RANGE: Early Danian (P1a subzone - within P2 zone) (Blow, 1979)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	mod. comm.	**49/10-1**		**49/24-3**	rare
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		v.common
Reculver					

Eoglobigerina eobulloides "s.l." (MOROZOVA)

Recommended source for illustration:
Blow (1979) pl.55, figs 1-4; pl.57, figs 3-4; pl.60, figs 2-3,9; pl.61, fig.1;
pl.65, figs 8-9; pl.66, figs 6,9; pl.70, figs 3-6, 9-10; pl.73, figs 1-3,8-9; pl.74, fig.6;

1959 *Globigerina (Eoglobigerina) eobulloides* MOROZOVA p.1115, text figs 1a-c

1979 *Eoglobigerina eobulloides* (Morozova): BLOW, p.1215, pl.60, fig.9;, pl.61, fig.1; pl.65, figs 8-9; pl.66, figs 6,9; pl.70, figs 3-4; pl.74, fig.6

1979 *Eoglobigerina eobulloides simplicissima* BLOW p.1217, pl.55, figs 1-4; pl.57, figs 3-4; pl.60, figs 2-3; pl.70, figs 5-6, 9-10; pl.73, figs 1-3, 8-9

DIAGNOSIS: Test small with a low trochospire, 4-4.5 chambers in the final whorl increasing slowly to moderately rapidly in size, aperture umbilical to extraumbilical, a low asymmetrical arch with a thin lip.

REMARKS: Two subspecies are occasionally recognised: *E.e.eobulloides* has a relatively slow chamber size increase rate and generally fewer (i.e. 4) chambers than *E.e.simplicissima*. *E.e.simplicissima* is also proported to have a "more laterally restricted aperture" (Copestake & Dyer, 1981). The two subspecies were difficult to separate in the material studied and so have been recorded as "s.l.".

E.trivialis (*E.trivialis* "s.l." herein) is similar but has a more distinct trochospire and a more umbilical aperture.

Morozovella pseudobulloides is also similar but has a flatter trochospire and a more extraumbilical aperture.

RANGE: *E.eobulloides s.s* ranges from the base of the Danian into the lower part of zone P2 (i.e. mainly early Danian) (Blow, 1979). The *E.e.simplicissima* subspecies ranges only to the top of zone P1 (early Danian) (Blow, 1979). Where the *simplicissima* subspecies can be differentiated, its top is used to partly define Bioevent M1 of Mudge & Copestake (1992).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	abundant	**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		abundant
Reculver					

Eoglobigerina trivialis "s.l." (SUBBOTINA)

Recommended source for illustration:
Blow (1979) pl.55, fig.9; pl.57, figs 7-8; pl.61, fig.8; pl.65, figs 1-3;
pl.66, figs 4,7; pl.69, figs 8-9; pl.70, fig.8; pl.74, figs 3-5; pl.79, figs 1-2

1953 *Globigerina trivialis* SUBBOTINA p.64, pl.4, figs 4, 6-7

1979 *Eoglobigerina trivialis* (Subbotina): BLOW, p.1224, pl.65, figs 1-3; pl.66, figs 4,7; pl.69, fig.9; pl.70, fig.8; pl.74, figs 3,5; pl.79, figs 1-2

1979 *Eoglobigerina* aff. *trivialis* (Subbotina): BLOW, p.1228, pl.61, fig.8; pl.69, fig.8; pl.74, fig.4

1979 *Eoglobigerina* cf. *trivialis* (Subbotina): BLOW, p.1229, pl.55, fig.9; pl.57, figs 7-8

DIAGNOSIS: Test small, a moderate to high trochospire with 4 inflated, subglobular, tightly coiled chambers in the final whorl enlarging slowly in size, umbilicus small and deep, aperture a low arch or slit, mainly umbilical but slightly asymmetrical.

REMARKS: *E.edita* (*E.edita* "s.l." herein) also has a relatively high trochospire but has 5 chambers in the final whorl.

Two "variants" have been recognised by Blow (1979) which appear to have some stratigraphical utility. *Eoglobigerina* aff. *trivialis* (*sensu* Blow, 1979) has a more strongly pronounced trochospire than *E.trivialis sensu stricto*, whereas *Eoglobigerina* cf. *trivialis* (*sensu* Blow, 1989) has more closely appressed and embracing chambers and also has an additional bulla-like chamber present across the umbilicus. These variants, which are very rare in the material studied, are not taxonomically separated here.

RANGE: The "group" is common in the early Danian (zone P1) but ranges in total throughout the Danian. According to Blow (1979), *E.trivialis* sensu stricto ranges just into the lowest part of the Late Palaeocene (zone P3). *E.*aff.*trivialis* does not, however, range above the early Danian (zone P1). *E.*cf.*trivialis* appears to range just slightly higher than the top of zone P1 although is recorded as possibly ranging to the top of the Danian (zone P2) by Blow (1979). Where material permits differentiation of the three forms, the highest occurrences of *E.trivialis* and *E.*aff.*trivialis* are used to partly define Bioevents M2 and M1 (respectively) of Mudge & Copestake (1992). Event M2 occurs at the Danian-Thanetian boundary (within the Maureen Formation) and event M1 occurs within the Danian and marks the top of the Chalk Group, Ekofisk Formation.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		mod. comm.
Reculver					

Genus *Globoconusa* Khalilov, 1956

Globoconusa daubjergensis **(BRONNIMANN)**

Recommended source for illustration:

Toumarkine & Luterbacher (1985) fig. 11.6-7

1953 *Globigerina daubjergensis* BRONNIMANN p.340 fig.1

1956 *Globoconusa conusa* KHALILOV p.249 pl.5 fig.2

1961 *Globigerina kozlowskii* BROTZEN & POZARYSKA p.161 pl.1-3

1975 *Globigerina daubjergensis* Brönnimann: STAINFORTH *et al.* p.181 fig.45

1976 *Globoconusa daubjergensis* (Brönnimann): HOFKER p.34 fig.1

1979 *Globigerina daubjergensis* Brönnimann: CRITTENDEN p.48 pl.7 figs.A-C

1979 *Globastica daubjergensis*: (Brönnimann): BLOW p.1235, pl.74, figs 7-9; pl.256, figs 1-9; pl.257, figs 3-4

1983 *Globoconusa daubjergensis* (Brönnimann): KING p.36

1985 *Globoconusa daubjergensis* (Brönnimann):TOUMARKINE & LUTERBACHER p.106 fig.11.6-7

DIAGNOSIS: Test small, a high trochospire with 3-4 spherical subglobular chambers in the final whorl which increase rapidly in size. Umbilicus shallow and almost closed, aperture umbilical to slightly extraumbilical, a small arch almost circular in appearance. Sutures depressed, test surface hispid.

REMARKS: This is a distinctive species, though rather small. Their appears to a chronological gradation in morphology with successive stages displaying an increased spire height. Supplementary sutural openings also begin to appear on the spiral side and final stages display an apertural bulla (Hofker, 1962 and Hansen, 1970). These later stages have been named as *Globigerina conusa* Khalilov and *Globigerina kozlowskii* (Brotzen & Pozaryska). Premoli-Silva (1977) suggests that the *Globoconusa daubjergensis* "plexus" evolved via a short-axis "*Guembelitria*" stage and, in turn, evolved into a "*Globigerina*", "*Globigerinoides*" and finally a "*Catapsydrax*" stage.

Blow (1979) recognises three species of *Globastica* (*G.daubjergensis, G.kozlowskii* and *Globastica type I (?aff.microcellulosa)*. He also separately distinguishes *Globoconusa conusa* as a representative of the Heterohelicacea.

RANGE: Early Palaeocene - a Danian index form. However, most authors agree that the evolutionary first appearance of *G.daubjergensis* occurs above the base of the Danian, at the base of the *G.pseudobulloides* Zone (Stainforth *et al.*, 1975) = P1a *G.pseudobulloides* Subzone of Blow (1969). I.e. it does not occur until above the basal Danian *G.eugubina* Zone of Stainforth *et al.*, 1975 (*G.(T.)longiapertura*, Pα Zone of Blow (1979).

Its highest worldwide stratigraphic occurrence is thought to be no higher than the Early Palaeocene (Danian) *G.trinidadensis* Zone of Stainforth *et al.*(1975) (within Zone P2 *G.praecursoria praecursoria* Zone of Blow, 1979 and at the top of Subzone P1d *M.trinidadensis* of Toumarkine & Luterbacher, 1985). However, in the North Sea area it's "top" is not normally encountered until part-way into the Early Palaeocene, Danian and is often close to the top of the Chalk Group, Ekofisk Formation. King (1983, 1989) uses the stratigraphic top of this species to define the top of Subzone NSP1a of earliest Palaeocene (basal Danian) age, whereas Vinken (1988) uses the same event to define the top of Zone NPF1.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	?
29/25-1		**49/20-2**		**49/24-4**	?
44/2-1		**49/24-2**	rare	**49/25-2**	
ONSHORE					
Wormingford Mere		?	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		common
Reculver					

Family GLOBOROTALIIDAE Cushman, 1927
Genus *Globorotalia* Cushman, 1927
***Globorotalia archeocompressa* BLOW**
Recommended source for illustration:
Blow (1979) pl.56, figs 1-2; pl.58, figs 2,6-9; pl.64, figs 5,9; pl.68, figs 5-6

1979 *Globorotalia archeocompressa* BLOW p.1049, pl.56, figs 1-2; pl.58, figs 2,6-9; pl.64, figs 5,9; pl.68, figs 5-6

DIAGNOSIS: Test small, a very low trochospire with early whorls somewhat "sunk-into" the test. Approximately 5.5 subglobular, equidimensional chambers in the final whorl, increasing moderately slowly in size. Margin well rounded, periphery lobate. Aperture a low interiomarginal arch with a flange-like lip, wall finely perforate and smooth.

REMARKS: Blow (1979) described a number of Early Palaeocene globorotaliid taxa which appear to be ancestral to the *Planorotalites* lineage, beginning with *P.compressa* (Plummer). They are all of very similar morphology, essentially 5 chambered, well rounded (i.e. non-compressed) *Globorotalia* species with smooth walls, which are common in Danian (particularly early Danian) strata worldwide. Taxa included in this group include *G.archeocompressa*, *G.planocompressa* (see below) and *G.*cf.*compressa* (see discussion under *P.compressa*)

G.archeocompressa has more equidimensional chambers than *G.planocompressa* and has a lower trochospire. However, transitional forms occur between the two taxa, as well as between both the aforementioned species and *G.*cf.*compressa sensu* Blow (1979), making differentiation of all the taxa difficult in the poorly preserved material normally recorded herein.

RANGE: Restricted to the basal Palaeocene Pa zone - P1a subzone (Blow, 1979). Where identification is good, the occurrence of this species can prove the presence of the lowermost part of the Ekofisk Formation of earliest measurable Palaeocene age.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Globorotalia perclara LOEBLICH & TAPPAN

Recommended source for illustration:
Murray *et al.* (1989) pl.10.10, figs 28-30

1957 *Globorotalia perclara* LOEBLICH & TAPPAN

1989 *Globorotalia perclara* Loeblich & Tappan: MURRAY *et al.*, p.530, pl.10.10, figs 28-30

DIAGNOSIS: Test small, a low trochospire, spiral side almost flat, 5-6 subspherical chambers in the final whorl, sutures radial, periphery lobate, open umbilicus, pustulose ornament which is stronger on earlier chambers.

REMARKS: This small species is distinguished by its open umbilicus and very low trochospire.

RANGE: "Middle" Palaeocene - Early Eocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay	rare		**Stevns Klint**		
Reculver					

***Globorotalia planocompressa* SHUTSKAYA**

Recommended source for illustration:

Blow (1979) pl.68, figs 4,8-10; pl.71, figs 8-10

1965 *Globorotalia planocompressa* SHUTSKAYA p.180, pl1, fig.6

1979 *Globorotalia compressa planocompressa* Shutskaya: BLOW p.1067, pl.68, figs 4,8-10; pl.71, figs 8-10

DIAGNOSIS: Test small to medium, a low trochospire occasionally becoming moderately high in some specimens. Approximately 5.5 subglobular, somewhat tangentially elongate chambers in the final whorl, increasing moderately slowly in size. Margin well rounded, periphery lobate. Aperture a low interiomarginal arch with a flange-like lip, wall finely perforate and smooth.

REMARKS: This species differs from *G.archeocompressa* by the more tangentially elongate chambers and the relatively higher trochospire. *G.planocompressa* is very similar to *G.*cf.*compressa sensu* Blow (1979) and specimens of that variant have probably been included within *G.planocompressa* in this work (see discussion under *Planorotalites compressa*). Good stratigraphical control may be necessary to separate the two taxa (see "Range" below) and the rather large sample spacing available in this study (usually 30' cuttings samples) and the potential for caving problems, makes the separation extremely difficult.

RANGE: Essentially restricted to the early Danian (P1 zone). The range of *G.*cf.*compressa* is, according to Blow (1979), P1a subzone - near top of zone P2 (early, but not earliest - late Danian).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	?	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		?	**Stevns Klint**		
Reculver					

Globorotalia reissi LOEBLICH & TAPPAN

Recommended source for illustration:
Murray *et al.* (1989) pl.10.10, figs 23-25

1957 *Globorotalia reissi* LOEBLICH & TAPPAN

1989 *Globorotalia reissi* Loeblich & Tappan: MURRAY *et al.* p.532, pl.10.10,figs 23-25

DIAGNOSIS: Test small to medium, a low trochospire. Approximately 6 subglobular, somewhat compressed chambers in the final whorl, increasing moderately slowly in size. Margin well rounded, periphery slightly lobate. Umbilicus small and shallow. Aperture a low interiomarginal arch, wall finely perforate and smooth.

REMARKS: This species, recorded from well 49/25-2 only, is similar, though unrelated, to *M.uncinata*, from which it differs in lacking any degree of angulo-conical chamber shape.

RANGE: Early Eocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	mod. comm.
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Globorotalia sp.A, ?sp.nov.

Pl.1 Fig.C

DIAGNOSIS: Test small, a very low trochospire, almost planispiral. Numerous (7-9) globular chambers in the final whorl increasing slowly in size. Periphery well rounded and lobate. 1-2 early whorls clearly visible on the spiral side, umbilicus wide and open. Sutures radial and depressed.

REMARKS: Large numbers of this taxon were recorded from several sidewall core samples from well 29/25-1. The vast majority of specimens are orange-stained, a feature often noted in the preservational characteristics of certain Early Eocene planktonic foraminifera in the North Sea Basin (see the discussion under *Subbotina linaperta*). The morphology of the specimens recorded from 29/25-1 are similar to the Cretaceous species *Hedbergella planispira* Tappan.

In the same sidewall core samples, large numbers of specimens of a similar planktonic foraminiferal type (designated herein as *Globorotalia* sp.B ?sp.nov.) were also recovered. Neither taxa were recorded from cuttings material from the same well leading to the possible assumption that the sidewall cores in which these taxa were recovered were either miss-shot or miss-labelled.

H.planispira is commonly recorded, in abundance, from late Albian intervals in the North Sea Basin, although the particular colouration is not characteristic. *H.infracretacea* is commonly recorded, in abundance, from early Aptian strata in the same area and does display a distinctive orange/red staining. Both taxa, however, have a range encompassing the Barremian - Cenomanian interval in the North Sea area.

Various workers (Mears *pers. comm.*, Jutson *pers. comm.* and Holmes *pers. comm.*) have noticed similar "anomalous" occurrences of these taxa from Early Tertiary intervals elsewhere in the North Sea Basin. There appears to be a reworking "event" of Early Cretaceous taxa into Late Palaeocene sediments which is sporadically recorded in the North Sea area, possibly from exposed rotated fault blocks with Early Cretaceous (probably Aptian-Albian) crests. The specimens recorded from the 29/25-1 well are, however, relatively well preserved and show little physical signs of abrasion associated with reworking.

Both taxa recorded here (*Globorotalia* sp.A and sp.B) are of extremely small size and thus may be juvenile specimens of other taxa. This small size could account for the apparent absence of these species in "normal" industrial slide preparations, in which the finest size fraction (75μm -125μm) is seldom examined.

To the author's knowledge, no planktonic species similar to this taxon have been recorded from Late Palaeocene - Early Eocene strata from the North Sea Basin. Other contemporaneous species are distinctly different morphologically; *Morozovella trinidadensis* (Early - lower "Middle" Palaeocene) has generally fewer chambers, *Morozovella uncinata* (Early - lower "Middle" Palaeocene) has more angulo-conical older chambers, *Acarinina pentacamerata* (Early - Middle Eocene) is more biconvex and inflated and *Pseudohastigerina* spp. are wholly planispiral.

Globorotalia (Turborotalia) kugleri Bolli, *Globorotalia (Turborotalia) pseudokugleri* Blow, and *Globorotalia (Turborotalia) gemma* Jenkins, are recorded by Hooyberghs (1983) from the Rupel and Berchem Formations (Oligocene and Miocene respectively) of Belgium. These taxa have similar gross morphologies to *Globorotalia* sp.A but would require a significant increase in their downward range to permit the specimens recorded in this study to be assigned to any of these taxa.

Globigerina eugubina Luterbacher & Premoli-Silva, is also superficially similar and of a comparable small size although this species does not range above the basal Palaeocene Pα Zone.

RANGE: The occurrences of both morphotypes fall within intervals designated (by other biostratigraphic evidence) as Late Palaeocene - earliest Eocene.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	abundant	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Globorotalia sp.B, ?sp.nov.

Pl.1 Fig.D

DIAGNOSIS: Test a fairly small, medium trochospire with a convex spiral side. 5-6 globular chambers in the final whorl increasing moderately rapidly in size. Periphery well rounded and lobate. 1-2 early whorls visible on the spiral side, umbilical side closed to slightly open.

REMARKS: Like *Globorotalia* sp.A (above), this species has close morphological affinity with Cretaceous taxa i.e. *Hedbergella delrioensis* (Carsey) / *H. infracretacea* (Glaessner) and displays an orange preservational colour.

RANGE: The occurrences of both morphotypes fall within intervals designated (by other biostratigraphic evidence) as Late Palaeocene - earliest Eocene.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	abundant	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Planorotalites* Morozova, 1957

Planorotalites chapmani **(PARR)**

Recommended source for illustration:

Toumarkine & Luterbacher (1985) fig.12.5-8

1938 *Globorotalia chapmani* PARR p.87 pl.9 figs.8-9

1957 *Globorotalia elongata* Glaessner: BOLLI p.77 pl.20 figs.11-13

1957 *Globorotalia ehrenbergi* BOLLI p.77 pl.20 figs.18-20

1957 *Globorotalia troelseni* LOEBLICH & TAPPAN p.196 pl.60 fig.4 pl.63 fig.5

1957 *Globorotalia elongata* Glaessner: LOEBLICH & TAPPAN p.189 pl.45 fig.5 pl.46 fig.5 pl.48 fig.5 pl.49 fig.7 pl.54 figs.1-5 pl.59 fig.4 pl.60 fig.9 pl.63 fig.2

1964 *Globorotalia chapmani* Parr: McGOWRAN p.85 pl.1 figs.1-9

1973 *Globorotalia chapmani* Parr: SAMANTA p.454 pl.13 figs.13-15

1975 *Globorotalia chapmani* Parr: STAINFORTH *et al.* p.176 fig.42

1979 *Globorotalia chapmani* Parr: CRITTENDEN p.86 pl.2 figs M,N,O

1979 *Globorotalia (Turborotalia) chapmani* Parr: BLOW p.1059, pl.106, fig.1, pl.116, figs 1-5

1985 *Planorotalites chapmani* (Parr): TOUMARKINE & LUTERBACHER p.108 fig.12.5-8

DIAGNOSIS: Test a very low trochospire, smooth, lenticular and biconvex. Some specimens may be almost planispiral although the aperture is always extends onto the umbilical side and normally is a moderately high arch. 4-6 chambers in the final whorl increasing fairly rapidly in size, the final chamber can occupy up to one third of the whorl. Periphery lobate and subacute with an imperforate marginal band which gives the impression of a keel. Sutures depressed, curved on the spiral side, radial to slightly curved on the umbilical side.

REMARKS: *P.chapmani* is the direct descendant of *P.compressa* from which it differs in its subacute peripheral margin with an imperforate margin giving the impression of a keel. It is the ancestor of *P.pseudomenardii* which possesses a true keel. In the Late Palaeocene, *P.chapmani* morphologically intergrades with the almost wholly planispiral *Globanomalina wilcoxensis*. All of the specimens illustrated by Blow (1979) display very well rounded peripheries with no apparent imperforate band, globular to subglobular chambers, and between 6-7 chambers in the final whorl - all characteristics of the species *Globanomalina wilcoxensis*. However, the apertures for each specimen are clearly placed towards the umbilical sides, hence their presumed assignment to *P.chapmani*.

Blow (1979) suggests that the Parr's holotype of *P.chapmani* is in fact a member of the Valvulineridae (benthonic foraminifera). If substantiated, the correct name for this taxon would be *P.ehrenbergi*.

RANGE: Latest Middle Palaeocene to Early Eocene (Zones P3 - P6 of Blow, 1969 in Toumarkine & Luterbacher, 1985) (*G.pusilla pusilla* Zone to *G.subbotinae* Zone of Stainforth *et al.*, 1975). Blow (1979) however, indicates the range of this species to be from the base of Zone P5 to the top of Zone P7 i.e. wholly within the Early Eocene.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	?	**49/10-1**	rare	**49/24-3**	
29/25-1	?	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	?
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver		?			

Planorotalites compressa **(PLUMMER)**

Recommended source for illustration:

Toumarkine & Luterbacher (1985) fig. 12.1-2

1926 *Globigerina compressa* PLUMMER p.135 pl.8 fig.11

1957 *Globorotalia compressa* (Plummer): BOLLI p.77 pl.20 figs.21-23

1971 *Globigerina compressa* var. *compressa* Plummer: SUBBOTINA p.63 pl.2 figs.4-5

1975 *Globorotalia compressa* (Plummer): STAINFORTH *et al.* p.178 fig.43

1979 *Globorotalia compressa* (Plummer): CRITTENDEN p.88 pl.2 figs.G,H,I

1979 *Globorotalia (Turborotalia) compressa compressa* (Plummer): BLOW p.1062, pl.75, figs 10-11, pl.78, figs 5-10, pl.233, figs 1-3, pl.248, figs 1-3, pl.254, figs 1-3, pl.257, figs 5-7

1985 *Planorotalites compressa* (Plummer):TOUMARKINE & LUTERBACHER p.107 figs.12.1-2

DIAGNOSIS: Test a low trochospire, smooth, lenticular and biconvex. 4-5 chambers in the final whorl increasing somewhat rapidly in size, early whorls visible. Final chamber (s) is elongated radially and comprises one quarter to one third of the final whorl. Periphery lobate with a rounded to subacute margin with no keel or imperforate band. Sutures depressed and radial though slightly curved on umbilical side. Aperture a low umbilical to extraumbilical arch, occasionally with a thin lip.

REMARKS: *P.compressa* is the forerunner of a Palaeocene lineage of lenticular, compressed forms of which *P.chapmani* is the direct descendant, subsequently leading to *P.pseudomenardii* with the acquisition of a true keel. The genus *Planorotalites* Morozova, 1957 was erected to include those species, formerly assigned to *Globorotalia*, with compressed and smooth-walled tests (see Toumarkine & Luterbacher, 1985 for discussion).

The origins of *P.compressa* itself are uncertain, though Blow (1979) describes stratigraphically older taxa (*G.compressa planocompressa* and *G.archeocompressa*) with probable affinities. These are referable to the genus *Globorotalia* as they lack the essentially compressed nature of the test, characteristic of *Planorotalites*.

Blow also recognises a form designated as *Globorotalia* cf. *compressa* which differs from the nominate taxon by possessing subrounded peripheral margins in axial view. This morphology is also extremely similar to *G.planocompressa* and specimens possibly referable to this "cf." form may have been included with *G.planocompressa* in this work (see discussions under those respective species).

RANGE: Early to Middle Palaeocene (intra *G.pseudobulloides* Zone to *G.angulata* Zone of Stainforth *et al.*, 1975; Subzone P1c to P3 of Blow, 1969; Subzone P1b to P3 of Blow, 1979).

In the North Sea, King (1983) considers *P.compressa* to range throughout Zone NSP1 (Early to earliest Late Palaeocene). Its highest occurrence is often associated with the top of the Maureen Formation and it ranges down into the Ekofisk Formation. However, the stratigraphic top of *P.*cf.*compressa* is used to partly define Bioevent M2 of Mudge & Copestake (1992). This event occurs at the Danian-Thanetian boundary.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	mod. comm.	**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Family TRUNCOROTALOIDIDAE Loeblich & Tappan, 1961

Genus *Acarinina* Subbotina, 1953

***Acarinina bullbrooki* (BOLLI) "group"**

Recommended source for illustration:

Toumarkine & Luterbacher (1985) fig. 29.4-10 (+1-3, 11-22 for "group")

1957 *Globorotalia bullbrooki* BOLLI p.167, pl.38, fig.5

1975 *Globorotalia bullbrooki* Bolli: STAINFORTH *et al.* p.174, fig.40

1979 *Globorotalia (Acarinina) bullbrooki* (Bolli): BLOW p.915, pl.149, figs 8-9, pl.155, figs 1-8, pl.171, figs 1-3 & 7-9

1985 *Acarinina bullbrooki* (Bolli): TOUMARKINE & LUTERBACHER p.130, fig. 29.4-10

DIAGNOSIS: The "group" comprises those species of *Acarinina* with generally 4-5 (occasionally more) subangular to conical chambers in the final whorl, and a subrounded to subacute periphery. Other more general characteristics are a low trochospire; generally planoconvex test shape; an extraumbilical aperture; a low arch and a spinose wall, especially on the umbilical side.

REMARKS: Eocene assemblages worldwide contain abundant spinose globorotaliids included by most authors (e.g. Blow, 1979; Toumarkine & Luterbacher, 1985) in this genus. Taxonomy is discussed by Stainforth *et al.* (1975), Toumarkine & Luterbacher (1985) and, more extensively, by Blow (1979). As detailed study of the Eocene as a whole lies outside the realm of this thesis, spinose planktonic foraminifera recorded herein which are referable to *Acarinina* have been classified under four taxonomical groupings: the *A.bullbrooki* "group"; *A.soldadoensis* "group"; *A.mckannai* "group"; and the *A.wilcoxensis* "group". Although certain members of these groupings can be found in Upper Palaeocene strata.

The *A.bullbrooki* "group" includes the nominate taxon plus *Acarinina spinuloinflata* (Bandy) and *Acarinina broedermanni* (Cushman & Bermudez). See Toumarkine & Luterbacher (1985) for a discussion on this group. They are, essentially, the more plano-convex forms recorded in this study.

RANGE: The "group" as a whole ranges from the late Early Eocene - late Middle Eocene, zones P8 - P14 (Toumarkine & Luterbacher, 1985).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Acarinina mckannai (WHITE) "group"

Recommended source for illustration:
Toumarkine & Luterbacher (1985) fig. 18.3-6 (+1-2 for "group")

1928 *Globigerina mckannai* WHITE p.194, pl.27, fig.16
1975 *Globigerina mckannai* White: STAINFORTH *et al.*, p.205, fig.66
1979 *Muricoglobigerina mckannai* (White): BLOW p.1129, not illustrated
1985 *Acarinina mckannai* (White): TOUMARKINE & LUTERBACHER, p.116, fig. 18.3-6

DIAGNOSIS: The "group" comprises those species of *Acarinina* with generally 4-7 tightly coiled chambers in the final whorl, a well rounded periphery and a high trochospire. Other more general characteristics are a very spinose surface and an almost subglobular appearance.

REMARKS: Toumarkine & Luterbacher (1985, p.116) remark that *Acarinina* species of this group, which includes the nominate taxon plus *Acarinina nitida* (Martin), "...may become very frequent in Middle Palaeocene to basal Eocene assemblages outside the tropical realm in which typical *i.e. conical* (author's italics) *Morozovella* species are missing."

This group contains the more globular acarininiids recorded in this study.

RANGE: The "group" ranges from the "Middle" Palaeocene (zone P3) to mid Early Eocene (zone P7) with *A.mckannai* becoming extinct near the end of the Palaeocene whereas *A.nitida* is essentially Early Eocene restricted (Toumarkine & Luterbacher, 1985).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Acarinina soldadoensis (BRONNIMANN) "group"

Recommended source for illustration:
Toumarkine & Luterbacher (1985) fig. 17.-1-3 (+4-7 for "group")

1952 *Globigerina soldadoensis* BRONNIMANN p.7, pl.1, figs 1-9

1975 *Globigerina soldadoensis s.l.* Brönnimann: STAINFORTH *et al.*, p.228-9, figs 86-87

1979 *Muricoglobigerina soldadoensis soldadoensis* (Brönnimann): BLOW p.1120, pl.98, figs 1-3, pl.107, figs 1-5, pl.109, fig.8, pl.110, fig.1, pl.124, figs 1,3 & 5, pl.131, figs 1-3, 6, pl.236, fig.6

1985 *Acarinina soldadoensis s.l.* (Brönnimann): TOUMARKINE & LUTERBACHER p.115-6, figs 17.1-2,3

DIAGNOSIS: The "group" comprises those species of *Acarinina* with generally 3.5-8 rather loosely coiled chambers in the final whorl and a well rounded periphery. Another more general characteristic is a very spinose surface.

REMARKS: This "group" is somewhat poorly defined morphologically but includes those acariniids outside other "groups" commonly found in the Late Palaeocene - Early Eocene interval (see Toumarkine & Luterbacher, 1985).

The group includes the nominate taxon (which can include the subspecies *A.s.soldadoensis* (Brönnimann) and *A.s.angulosa* (Bolli)), plus *Acarinina primitiva* (Finlay); a 3-4 chambered form and *Acarinina pentacamerata* (Subbotina); a 5-8 chambered form.

RANGE: The group as a whole ranges from late "Middle"? / Late Palaeocene (zone P3? / P4) to Middle Eocene (zone P11 / ?zone P12) with *A.primitiva* and *A.s.soldadoensis* being the only species to range down into the Palaeocene.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**	rare	**49/25-2**	?
ONSHORE					
Wormingford Mere		?	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Acarinina wilcoxensis (CUSHMAN & PONTON) "group"

Recommended source for illustration:
Stainforth *et al.* (1975) fig. 98 (+ fig.78 for "group")

1932 *Globorotalia wilcoxensis* CUSHMAN & PONTON p.71, pl.9, fig.10

1975 *Globorotalia wilcoxensis* Cushman & Ponton: STAINFORTH *et al.*, p.243, fig.98

1979 *Globorotalia (Acarinina) wilcoxensis wilcoxensis* (Cushman & Ponton): BLOW p.965, pl.112, figs 4-5, pl.113, figs 7-9, pl.114, figs 1 & 6, pl.122, figs 1-2, pl.132, fig.4, pl.140, figs 5-8, pl.199, figs 5-6, pl.200, figs 1-5, pl.201, figs 1-3, pl.250, figs 5-9

DIAGNOSIS: The "group" comprises those species of *Acarinina* with generally 4 chambers in the final whorl which are somewhat appressed. Other, more general characteristics are- a very spinose surface.

REMARKS: The *A.wilcoxensis* "group" is similar in general morphology to members of the *A.bullbrooki* "group" herein. The nominate taxon also has 4 chambers and a subacute periphery. *Acarinina pseudotopilensis* (Subbotina) is included within this group and is similar to *A.wilcoxensis* but has a well rounded periphery.

The two taxa are included here within the genus *Acarinina* because of the spinose nature of the wall surface.

The *A.wilcoxensis* and *A.bullbrooki* "groups" are separated herein by their different stratigraphical ranges.

RANGE: The "group" ranges from the Late Palaeocene - Early Eocene, zones P4 - P8 (Stainforth *et al.*, 1975; Toumarkine & Luterbacher, 1985).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	common
44/2-1		**49/24-2**	mod. comm.	**49/25-2**	mod. comm.
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Morozovella* McGowran, 1968

Morozovella praecursoria (MOROZOVA)

Recommended source for illustration:
Toumarkine & Luterbacher (1985) fig.13.5

1957 *Acarinina praecursoria* MOROZOVA p.1111 fig.1

1964 *Globorotalia praecursoria* (Morozova): LUTERBACHER p.652 fig.25

1975 *Globorotalia praecursoria* (Morozova): STAINFORTH *et al.* p.214 fig.74

not 1979 *Acarinina praecursoria* Morozova: BLOW p.945, pl.76 figs.4,8-9, pl.77 figs.2-5, pl.81 fig.3, pl.82 figs.1-3, pl.84 fig.2, pl.85 fig.9

1985 *Morozovella praecursoria* (Morozova): TOUMARKINE & LUTERBACHER p.110 fig.13.5

DIAGNOSIS: Test a low plano-convex trochospire with a flattened spiral side and inflated umbilical side. 5-8 chambers in the final whorl increasing gradually in size. The first 2-3 chambers of the final whorl are distinctly angulo-conical although remaining chambers are globular to ovate. Periphery slightly lobate, subangular at first becoming broadly rounded.

Sutures radial and depressed on umbilical side, recurved on early part of spiral side, becoming radial. Umbilicus fairly wide and open, aperture a low extraumbilical to umbilical arch, occasionally with a faint lip. Test wall spinose on initial whorls and on initial chambers of final whorl although the last few chambers are almost smooth. Ornamentation can also be concentrated on umbilical shoulders.

REMARKS: This species is distinguished from *M.uncinata* by having more chambers in the final whorl and displaying a transition from angulo-conical to globular ovate chamber shape. *G.trinidadensis* has globular chambers throughout the final whorl.

The species referred to as *Acarinina praecursoria* Morozova, by Blow (1979) would appear from the illustrations to more closely resemble *Morozovella uncinata* (Bolli). It is here included under the synonomy of that species.

This species is part of a group of important Palaeocene morozovellid taxa which are used worldwide for biostratigraphic and evolutionary studies. A discussion of this group follows below. Toumarkine & Luterbacher (1985) describe almost a dozen species of Palaeocene - Early Eocene angulo-conical morozovellids which are separated into 2 evolutionary lineages which are summarised in Table 8.1 (see also Berggren, 1966 and Luterbacher, 1966).

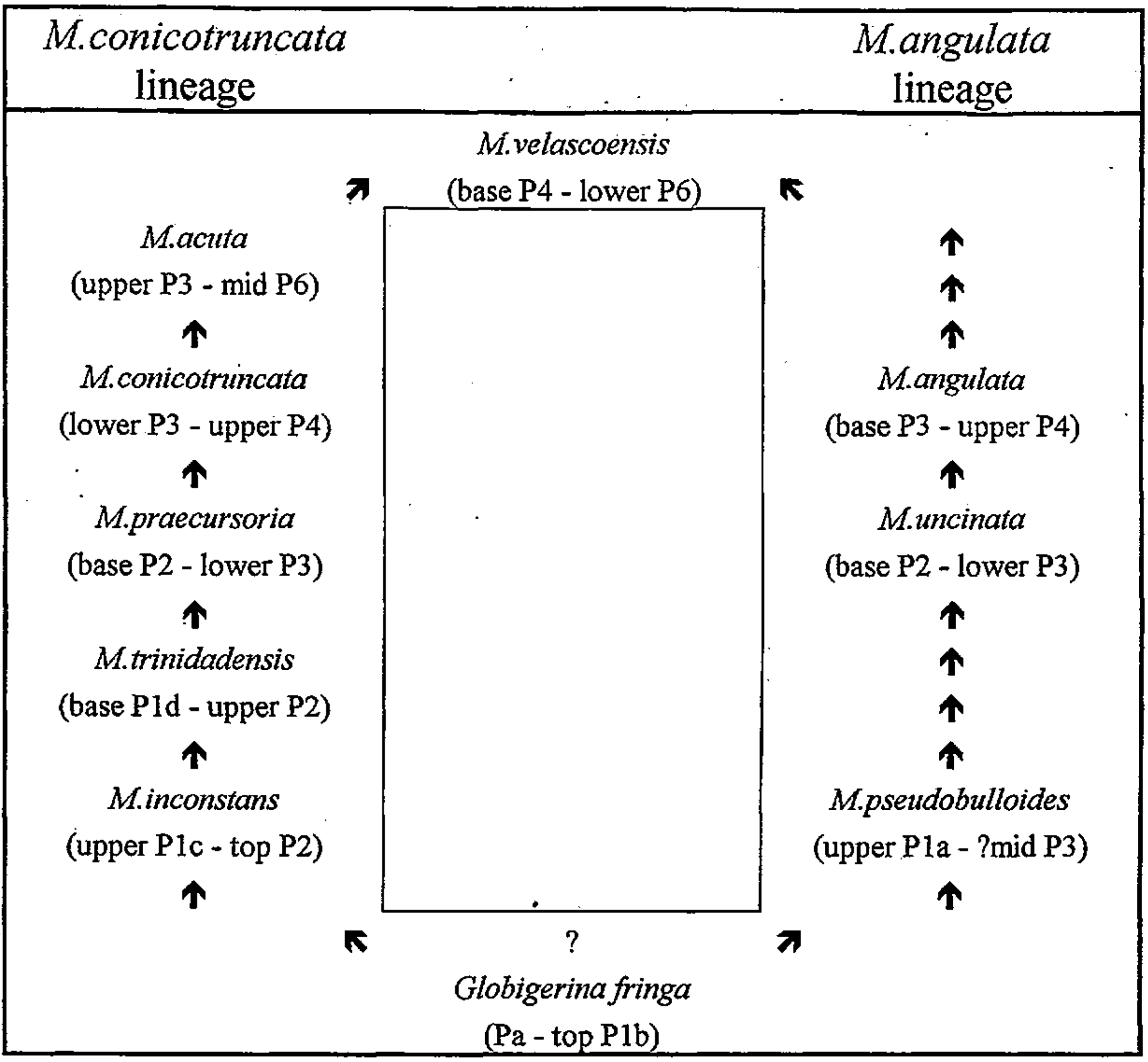


Table 8.1: Evolutionary lineages of certain Palaeocene planktonic foraminifera

The first, termed the *Morozovella conicotruncata* lineage, starts with forms with globular chambers (*M.inconstans*) and ends with angulo-conical forms with a heavy peripheral "keel" (carina or muricocarina) (*M.conicotruncata*). The second, termed the *Morozovella angulata* lineage, is parallel to the *M.conicotruncata* lineage and demonstrates a virtually identical and contemporaneous evolution from globigeriniid forms (*M.pseudobulloides*) to morozoveliid forms (*M.acuta*). Toumarkine & Luterbacher (1985) state that,

> *"At all levels, typical representatives of the two lineages are linked by intermediate forms. This parallel and interlinked development probably indicates that we are not dealing with two separate phylogenetic lineages, but rather with a uniform plexus of which the two lineages described here represent the easily distinguishable forms."*

Corfield & Granlund (1988) have also studied these lineages using biometric forms of analyses. They retain the ancestral species (*M.pseudobulloides*) in the genus *Subbotina* and also recognise intermediates forms between *M.uncinata* and *M.angulata* (*M.praeangulata*), and between *M.angulata* and *M.velascoensis* (*M.angulata* forma *protocarina*). They arrange Palaeocene morozovellids into three groups based on relative morphological organisation:

1) "Primitive" types - *S.pseudobulloides, M.trinidadensis, M.praecursoria* and *M.uncinata.*
2) "Intermediate" types - *M.praeangulata, M.angulata, M.conicotruncata* and *M.angulata* forma *protocarina.*
3) "Late stage" types - *M.velascoensis, M.occlusa* and *M.edgari.*

Thus, they regard this sequence of forms as one evolutionary lineage with the important evolutionary trends described below:

- The development of an angulo-conical test from a globigeriniform ancestor.
- The acquisition of a peripheral test muricocarina (the pseudokeel).
- The development of muricae upon the surface of the test.

To further complicate matters, Boersma & Premoli-Silva (1983) suggest that there may be as many as three lineages involved.

In the North Sea offshore, angulo-conical Palaeocene morozovellids are rarely encountered or absent altogether. Copestake & Dyer (1981 unpublished research demonstration at the University of Leicester) stated that *M.angulata* does not occur in the North Sea Basin (offshore). It has, however, been recorded from some onshore sequences:

- The Calcarenite of Mechelen aan de Maas (P3 Zone) at 290.5m in the Mechelen aan de Maas well, Belgium (Hooyberghs, 1983).
- A single specimen from the Svedala borehole, Skane and a single specimen from Denmark (Pozaryska & Szczechura, 1976)
- The Tuffeau de Lincent (G.velascoensis Zone) and the Givry 318 well, Belgium (El-Naggar, 1967, 1969).

However, King (in a pers. comm. to Crittenden, 1986) regards El-Naggar's specimens as misidentifications.

Crittenden (1981) has recorded (but not illustrated) a specimen designated as *Globorotalia cf. angulata* from well 49/24-2 (2080'-2110'). Crittenden also records three specimens of *G.uncinata* from the same well.

Clearly, these two species at least, otherwise globally widespread, are at or close to the limits of environmental tolerance in the North Sea Basin. Specimens of *M.angulata* have been recorded from the Palaeocene of the North Atlantic area in boreholes drilled in the West Shetland area and Faeroe Basins (Crittenden, 1986). Rare specimens of this, and related species, may have been introduced into the Palaeocene North Sea by wind and current action. The palaeogeography of this area during the Late Palaeocene (Chapter 2.3.2) suggests that a marine connection may have existed from the North Sea into the Northeast Atlantic Ocean via the Shetland Trough. This was caused by tectonic separation of the NW European and Greenland plate systems which subsequently led to the full opening of the northern Atlantic Ocean in Early Eocene times.

This group of planktonic foraminifera are clearly important in terms of biostratigraphy. Their apparent scarcity in (particularly offshore) sample material may be due (in addition to palaeoenvironmental factors discussed above) in part to their somewhat small size and thus may be missed in typical "industrial" preparations. Large amounts of material may be required in order to yield adequate numbers of specimens for meaningful research. Unfortunately, sample size from boreholes in this study were often extremely small which accounts for the paucity of individuals from this interesting group.

RANGE: *M.praecursoria* ranges from the base of Zone P2 to the middle part of Zone P3 (Toumarkine & Luterbacher, 1985) (= *G.uncinata - G.angulata* Zones of Stainforth *et al.*, 1975).

These authors include these Zones within the so-called "Middle" Palaeocene of classic tropical zonation schemes (see also Bolli, 1957; Loeblich & Tappan, 1957; Blow, 1969 and Berggren & Van Couvering, 1974).
The North Sea Palaeocene is, however, subdivided into Early (Danian) and Late (Thanetian) only. The boundary is drawn at the junction between Zones P2 and P3 (see Crittenden, 1986). The rarity of this species in the samples studied cannot add any further information to the knowledge of it's stratigraphic range in the North Sea Basin. However, it appears to give a reasonable indication for basal Thanetian age sediments where present.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		49/10-1		49/24-3	?
29/25-1		49/20-2		49/24-4	
44/2-1		49/24-2	?	49/25-2	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Morozovella pseudobulloides (PLUMMER)

Recommended source for illustration:
Toumarkine & Luterbacher (1985) fig. 14.1-2

1926 *Globigerina pseudobulloides* PLUMMER p.33 pl.8 fig.9

1953 *Globigerina compressa* var. *pseudobulloides* Plummer: SUBBOTINA p.55 pl.2 fig.7

1957 *Globorotalia pseudobulloides* (Plummer): BOLLI p.73 pl.17 figs.19-21

1971 *Globigerina compressa* var. *pseudobulloides* Plummer: SUBBOTINA p.63 pl.2 fig.7, 11-14

1975 *Globorotalia pseudobulloides* (Plummer): CRITTENDEN p.98 pl.2 figs.J,K,L

1975 *Globorotalia pseudobulloides* (Plummer): STAINFORTH *et al.* p.216 fig.76

1979 *Globorotalia pseudobulloides* (Plummer): BLOW p.1096 pl.69 figs.2-3, pl.71 figs.4-5, pl.75 figs.2-3, pl.248 figs.6-8, pl.255 figs.1-6

1983 *Globorotalia pseudobulloides* (Plummer): KING p.36 pl.6 figs.22,28 as illustrated not figs.18-19 as stated in text.

1985 *Morozovella pseudobulloides* (Plummer): TOUMARKINE & LUTERBACHER p.110 figs.14.1-2

1987 *Subbotina pseudobulloides* (Plummer): CORFIELD pl.6.1

DIAGNOSIS: Test a low trochospire, almost equally biconvex with the spiral side slightly flattened. Generally 4-5 spherical to ovate chambers in the final whorl which increase fairly rapidly in size. Periphery rounded and lobate throughout the final whorl. Sutures depressed, radial on umbilical side, radial to slightly curved on the spiral side. Aperture a low umbilical to extraumbilical arch with a faint lip. Surface finely perforate to coarsely cancellate, mainly smooth.

REMARKS: *M.pseudobulloides* differs from *M.uncinata* in the possession of fewer and more globular chambers. This species is common and widespread within North Sea Danian assemblages both on- and off- shore.

Blow (1979) distinguished two related species, *G.cf.pseudobulloides* (with 5 chambers and an extraumbilical aperture ranging from Zones Pα - ?early P2) and *G.aff.pseudobulloides* (with 5-6 chambers and a well-rounded aperture ranging throughout the Pα Zone).

M.pseudobulloides is the earliest representative of the *M.angulata* lineage of Palaeocene morozovellids (see above under *M.praecursoria*). Its generic placement is uncertain and depends on the author's opinion as to its place in the Palaeocene morozovellid evolutionary process (e.g. Corfield (1987) and Corfield & Granlund (1988) prefer retention in *Subbotina* and Blow (1979) includes the species in *Globorotalia*).

Morphologically, the description of the species seems best suited to placement within *Globorotalia* rather than *Subbotina*, mainly due to the position of the aperture. However, Toumarkine & Luterbacher (1985) include the species within *Morozovella* on evolutionary grounds in that *M.pseudobulloides* is the ancestral forms of many other Palaeocene and early Eocene morozovellids (see above). This reasoning is followed in this study although retention of this taxon in *Globorotalia* also has validity.

Ironically, Corfield and Granlund (1988) exclude the species from *Morozovella* using the same reasoning. They agree that the species is ancestral to other Palaeocene and Early Eocene morozovellids though prefer to retain the species within the genus *Subbotina* arguing that the earlier forms of *Morozovella* (i.e. *M.pseudobulloides*) do not possess any of the features by which the later morozovellids are recognised.

RANGE: Early Palaeocene - early Late Palaeocene (Zone P1 to within Zone P3), Blow (1979) and Toumarkine & Luterbacher (1985) (=*G.pseudobulloides* Zone - mid *G.angulata* Zone of Stainforth *et al.*, 1975).

King (1983) illustrates its range as throughout Zone NSP1 (Early Palaeocene -basal Late Palaeocene) and its "top" (extinction) often coincides with that of *P.compressa*. This level lies above the top of the Chalk Group, Ekofisk Formation and the tops of these two taxa can be useful markers for the Maureen Formation (and equivalents).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	v.common	**49/10-1**		**49/24-3**	
29/25-1	rare	**49/20-2**	rare	**49/24-4**	
44/2-1		**49/24-2**	rare	**49/25-2**	?
ONSHORE					
Wormingford Mere		?	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		abundant
Reculver		?			

Morozovella uncinata (BOLLI)

Recommended source for illustration:
Toumarkine & Luterbacher (1985) fig.14.3-4

1957 *Globorotalia uncinata* BOLLI p.74 pl.17 figs.13-15

1964 *Globorotalia uncinata* Bolli: LUTERBACHER p.655 figs.30-31

1975 *Globorotalia uncinata* Bolli: STAINFORTH *et al.* p.239 fig.95

1975 *Globorotalia uncinata* Bolli: CRITTENDEN p.106 pl.1 figs.T,U

1979 *Acarinina praecursoria* Morozova: BLOW p.945, pl.76 figs.4,8-9, pl.77 figs.2-5, pl.81 fig.3, pl.82 figs.1-3, pl.84 fig.2, pl.85 fig.9

1984 *Morozovella uncinata* (Bolli): MANCINI p.278 pl.3 figs.4-6

1985 *Morozovella uncinata* (Bolli): TOUMARKINE & LUTERBACHER p.110 figs.14.3-4

DIAGNOSIS: Test a low trochospire with a flat or only slightly convex spiral side and inflated umbilical side. 5-6 chambers in the final whorl increasing somewhat rapidly in size. All chambers are subangular to conical in shape except the final chamber which is more rounded and globular. Periphery is slightly lobate, subangular to angular in the early part of the whorl, becoming rounded later. Sutures depressed, radial on the umbilical side, strongly curved backwards on the spiral side. Umbilicus narrow and deep, aperture a low umbilical to extraumbilical arch.

REMARKS: This species is ancestral to *M.angulata* and differs from *M.praecursoria* (its evolutionary counterpart in the *M.conicotruncata* lineage) in possessing a smaller number of chambers in the final whorl. The strongly recurved spiral side sutures are also characteristic.

Blow's (1979) illustrations of *Acarinina praecursoria* Morozova, appear to resemble more closely the morphology of *M.uncinata* in that specimens figured display angulo-conical tests (except the final chamber) and strongly recurved sutures on the spiral side.

The next step in the morozovellid evolutionary lineage in which *M.uncinata* occurs is the appearance of *M.angulata*, a species not recorded in this study though recorded rarely in surrounding areas of the North Sea Basin (see discussion under *M.praecursoria*).

This species' record in the North Sea is very rare being noted only by three specimens by Crittenden (1975 & 1986) from the 49/24-2 borehole. King (1983) expresses surprise at this record as this taxon has not been recorded elsewhere in Northwest Europe. El-Naggar (1969) has recorded *G.uncinata* from the Middle and Upper Danian of the Tuffeau de Ciply although King (1983) regards these specimens as misidentified. According to Crittenden (1986) "unpublished research" has yielded *M.uncinata* from boreholes drilled in the West Shetland area and Faeroe Basins. It is not unfeasible that rare specimens could have been introduced into the North Sea Basin by prevailing winds and currents from this part of the Northeast Atlantic where the taxon was presumably extant.

RANGE: "Middle" Palaeocene (basal Zone P2 to mid Zone P3), Blow (1969), Berggren & Van Couvering (1974) in Toumarkine & Luterbacher (1985). (=*G.uncinata* Zone to *G.angulata* Zone of Stainforth *et al.*, 1975).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	?	**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	?	**49/24-2**	?	**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Subbotina* Brotzen & Pozaryska, 1961

Subbotina triangularis **"s.l." (WHITE)**

Recommended source for illustration:

Blow (1979) pl.80, figs 2-9, pl.91, figs 7-9, pl.98, fig.6, pl.107, figs 8-9, pl.238, fig.6

1928 *Globigerina triangularis* WHITE p.195, pl.28, fig.1

1979 *Globigerina triangularis* White: CRITTENDEN p.74, pl.3 figs A-C

1979 *Subbotina triangularis triangularis* (White): BLOW pl.91, figs 7-9, pl.98, fig.6, pl.107, figs 8-9

1979 *Subbotina triangularis cancellata* BLOW pl.80, figs 2-9, pl.238, fig.6

DIAGNOSIS: Test medium to large, a low trochospire with 3.5 subglobular chambers in the final whorl increasing rapidly in size, test roughly triangular in outline. Sutures strongly depressed, aperture a curved umbilical to extraumbilical opening with a lip. Surface moderately cancellate.

REMARKS: Distinguished from other cancellate planktonic species of the genus by its triangular outline and somewhat smaller, less elongated aperture. Blow (1979) recognises two subspecies with different degrees of wall cancellation, *S.t.cancellata* showing coarser cancellation similar to that of *Subbotina triloculinoides*. Blow restricts the stratigraphical range of *S.t.cancellata* to wholly within the Palaeocene (zone P2 up to zone P4) whereas the "group" (*S.t.triangularis* of Blow, 1979) ranges into the Early Eocene (zone P2 to zone P8). Lack of good stratigraphical control in the samples studied here (i.e. because of caving effects) prevents adequate separation of the two subspecies here.

RANGE: Palaeocene - Early Eocene (Blow, 1979 - see above).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	mod. comm.	**49/10-1**	mod. comm.	**49/24-3**	mod. comm.
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1	rare	**49/24-2**	mod. comm.	**49/25-2**	rare
ONSHORE					
Wormingford Mere		**Lundsgaards Cliff**			
Pegwell Bay		**Stevns Klint**			
Reculver	?				

Subbotina triloculinoides (PLUMMER)

Recommended source for illustration:
Toumarkine & Luterbacher (1985) fig. 19.1-2

1926 *Globigerina triloculinoides* PLUMMER p.134, pl.8, fig.10

1975 *Globigerina triloculinoides* Plummer: STAINFORTH *et al.*, p.234, fig.92

1979 *Globigerina triloculinoides* Plummer: CRITTENDEN p.75, pl.3 figs V-X

1979 *Subbotina triloculinoides triloculinoides* (Plummer): BLOW p.1287, pl.74, fig.6, pl.80, fig.1, pl.98, fig.7, pl.238, fig.5, pl.248, figs 9-10, pl.255, fig.9, pl.257, fig.9, text figures M & N

1985 *Globigerina triloculinoides* Plummer: TOUMARKINE & LUTERBACHER p.117, fig. 19.1-2

1987 *Subbotina triloculinoides* (Plummer): CORFIELD p.98

DIAGNOSIS: Test small to medium, a low trochospire of 3 - 3.5 globular chambers in the final whorl increasing rapidly in size, the last occupying one-third to one-half of the whorl, equatorial outline trilobate, umbilicus shallow, aperture mainly umbilical, occasionally umbilical to extraumbilical with a distinct lip, wall coarsely perforate and reticulate.

REMARKS: *Globigerina patagonica* is similar but has less well developed surface reticulation. *S.triloculinoides* is ancestral to species from the Eocene *Subbotina linaperta - Subbotina eocaena* lineage (*S.linaperta* "group" (pars.) herein) which are larger and have a somewhat lower and longer apertural opening, distinctly umbilical to extraumbilical in nature. It is also very similar to the *Subbotina frontosa* (Bermudez) group of the younger Eocene and Oligocene.

The genus *Subbotina* was, according to Stainforth *et al.*, 1975, "poorly defined" by Brotzen & Pozaryska (1961) although was later emended by Blow (1979) who restricted the genus to those globigerine forms with pitted mural pores opening through pore-pits to give a reticulate surface pattern. *S.triloculinoides* is the type species.

RANGE: Palaeocene (but not youngest) (Stainforth *et al.*, 1975)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	mod. comm.	**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		mod. comm.
Reculver					

***Subbotina linaperta* (FINLAY) "group"**

Recommended source for illustration:

Stainforth *et al.* (1975) fig.63

1939 *Globigerina linaperta* FINLAY p.125, pl.13, figs 54-56
1975 *Globigerina linaperta* Finlay: STAINFORTH *et al.*, p.201, fig.63
1979 *Globigerina linaperta* Finlay: CRITTENDEN, p.60, pl.3, figs D-F
1979 *Subbotina linaperta* (Finlay): BLOW p.1276, pl.91, fig.8, pl.124, fig.9, pl.158, fig.8, pl.160, figs 6-8, pl.177, figs 4-6, pl.240, figs 5-6, text fig. N
1985 *Globigerina linaperta* Finlay: JENKINS p.275, fig. 6.2
1987 *Subbotina linaperta* (Finlay): CORFIELD p.98

DIAGNOSIS: Test medium to large, a low trochospire, tightly coiled with 3 (mainly) - 3.5 globular chambers in the final whorl, increasing rapidly in size, the final chamber occupies approximately one-half of the whorl. Aperture is a large, but low opening with a distinct lip. Test surface perforate and distinctly cancellate.

REMARKS: Differs from *S.triloculinoides* by the long, low aperture and the proportionately larger final chamber.

Stainforth *et al.* (1975) regard this species as part of a "closely knit plexus which displays great variability of coiling parameters" (p.202). They discuss no less than 17 individual taxa recorded in the literature from Palaeocene - Oligocene representatives of this plexus (p.294). The two main parameters, they state, which vary to give this plexus are (i) rate of chamber enlargement of adult chambers and (ii) degree of coiling tightness (see Stainforth *et al.*, 1975, fig.128, p.292).

It is likely that all these "subspecies" of *linaperta* have some justification for being separated, not least stratigraphical distribution, which could in turn lead to this group acquiring some more refined stratigraphical utility. However, due to lack of stratigraphical control in this study (i.e. samples contaminated by caved representatives from post-Palaeocene strata) not attempt at differentiation is made here, hence the "group" assignment to the taxon. Specimens possibly referable to the Eocene - Early Oligocene taxon *Subbotina eocaena* (Gumbel) (which has a less rapid rate of chamber size increase than *S.linaperta s.s.*) are also grouped into this category for the same reason.

RANGE: The "group" as a whole ranges from the latest Palaeocene - Oligocene (Stainforth *et al.*, 1975) (Toumarkine & Luterbacher, 1985). However, the occurrence of this plexus in abundance, provides a useful stratigraphical marker event in the lower Early Eocene of much of the North Sea area (see Text Figure 17). Representatives are commonly stained orange or red and occur in a unit correlatable with the Rosnaes Clay Formation in Denmark (see discussion Chapter 9.1).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	common	**49/24-3**	mod. comm.
29/25-1	-	**49/20-2**	rare	**49/24-4**	mod. comm.
44/2-1	common	**49/24-2**	mod. comm.	**49/25-2**	mod. comm.
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily HANTKENINACEA Cushman, 1927

Family GLOBANOMALINIDAE Loeblich & Tappan, 1984

Genus *Globanomalina* Haque, 1956

***Globanomalina micra* (COLE)**

Recommended source for illustration:

Toumarkine & Luterbacher (1985) figs 21.1-8

1927 *Nonion micrus* COLE p.22 pl.5 fig.12

1932 *Nonion danvillensis* HOWE & WALLACE p.51 pl.9 fig.3

1953 *Globigerinella micra* (Cole): SUBBOTINA p.88 pl.13 figs.16-17

1957 *Hastigerina micra* (Cole): BOLLI p.161 pl.35 figs.1-2

1959 *Pseudohastigerina micra* (Cole): BANNER & BLOW p.19 fig.4g-i

1964 *Globanomalina micra* (Cole): LOEBLICH & TAPPAN p.C655

1969 *Pseudohastigerina micra* (Cole): BLOW p.275 pl.53 figs.1, 4-6

1971 *Globanomalina micra* (Cole): JENKINS p.78 pl.2 figs.50-54

1975 *Pseudohastigerina micra* (Cole): STAINFORTH *et al.* p.207 fig.68

1979 *Pseudohastigerina danvillensis* Howe & Wallace: BLOW p.1181, pl.159, figs 6-7, pl.161, figs 2-7, pl.166, figs 2-10, pl.253, figs 10-12

1979 *Pseudohastigerina micra* (Cole): CRITTENDEN p.115 pl.1 figs.R,S

1983 *Pseudohastigerina micra* (Cole): KING p.36 pl.6 figs.30-31

1985 *Pseudohastigerina micra* (Cole):TOUMARKINE & LUTERBACHER p.118 figs.21.1-8

DIAGNOSIS: Test fairly small, planispiral or slightly asymmetrically planispiral with 5-7 moderately inflated subglobular chambers in the final whorl which increase moderately rapidly in size. Degree of lateral compression variable although normally laterally compressed with a more or less rounded periphery which becomes subacute in larger specimens. Earlier whorls generally visible from both sides. Sutures depressed, radial to

slightly curved, surface smooth. Aperture generally a low arch at the base of the apertural face of the last chamber, occasionally becoming bipartite in some specimens.

REMARKS: The classification of Loeblich & Tappan (1988) indicates the synonymous status of *Pseudohastigerina* with *Globanomalina* as proposed earlier by them in 1964. They state that the type species of both genera show evidence of their trochospiral ancestry in the possession of asymmetrical early whorls and aperture position. Illustrations of both topotypes (*Globanomalina ovalis* and *Nonion micrus*) show no appreciable differences and thus are regarded as congeneric. Berggren, Olsson & Reyment (1967) rejected Loeblich & Tappan's (1964) assignment, retaining the name *Pseudohastigerina*, a practice followed by almost all authors (e.g. Toumarkine & Luterbacher, 1985; Murray *et al.*, 1989).

G.micra is generally smaller than its ancestor *G.wilcoxensis*, and is more laterally compressed.

This species (along with *G.wilcoxensis*) appears quite fragile, yet Toumarkine & Luterbacher (1985) state that it is, in fact, very resistant to bad ecological conditions and may be a dominant species in high latitude assemblages. These two taxa were recorded in relatively high numbers (and, locally, were the dominant taxa) which would support this statement

RANGE: Early Eocene (P8 Zone) - Early Oligocene (P18/P19) (Bolli *et al.*, 1985).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	mod. comm.	**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1	rare	**49/24-2**	mod. comm.	**49/25-2**	mod. comm.
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Globanomalina wilcoxensis (CUSHMAN & PONTON)

Recommended source for illustration:
Toumarkine & Luterbacher (1985) fig.12.9-12

1932 *Nonion wilcoxensis* CUSHMAN & PONTON p.64 pl.8 fig.11
1960 *Hastigerina eocenica* BERGGREN p.85 pl.5 figs.1-2 pl.10 fig.2

1964 *Globanomalina wilcoxensis* (Cushman & Ponton): LOEBLICH & TAPPAN p.C665

1967 *Pseudohastigerina wilcoxensis* (Cushman & Ponton): BERGGREN, OLSSON & REYMENT p.278 figs.2-6

1975 *Pseudohastigerina wilcoxensis* (Cushman & Ponton): STAINFORTH *et al.* p.243 fig.99

1975 *Pseudohastigerina wilcoxensis* (Cushman & Ponton): CRITTENDEN p.115 pl.1 figs.N,O

1975 *Pseudohastigerina sharkriverensis* Berggren & Olsson: CRITTENDEN p.115 pl.1 figs.P,Q

1979 *Pseudohastigerina wilcoxensis* (Cushman & Ponton): BLOW p.1193, pl.159, figs 8-9, pl.161, figs 10-11, pl.252, figs 1-4

1983 *Pseudohastigerina wilcoxensis* (Cushman & Ponton): KING p.36 pl.6 figs.32-33

1985 *Pseudohastigerina wilcoxensis* (Cushman & Ponton): TOUMARKINE & LUTERBACHER p.108 fig.12.9-12

1989 *Pseudohastigerina wilcoxensis* (Cushman & Ponton): MURRAY *et al.* p.532 pl.10.11 figs.5-6

DIAGNOSIS: Test fairly small, planispiral or slightly asymmetrically planispiral with 5-7 moderately inflated subglobular chambers in the final whorl which increase moderately rapidly in size. Degree of lateral compression variable although periphery is normally rounded and lobulate. Earlier whorls generally visible from both sides. Sutures depressed, radial to slightly curved, surface smooth. Aperture generally a low arch at the base of the apertural face of the last chamber, occasionally becoming bipartite in some specimens.

REMARKS: *G.wilcoxensis* differs from *G.micra* in being somewhat larger and more inflated although the two are linked by intermediate forms (Stainforth *et al.*, 1975).

G.wilcoxensis evolved from *Planorotalites chapmani* in the Late Palaeocene by becoming almost wholly planispiral with a symmetrical aperture. However, the base of its range is not sharply defined owing to this gradual evolution. Blow (1979) places the inception of this species at the base of Zone P7 (very latest Palaeocene).

Some specimens recovered in this study display bipartite apertures positioned either side of the median line and extending towards the umbilicus on both sides, at the base of the apertural face. Crittenden (1975) illustrated this type and referred to it as *Pseudohastigerina sharkriverensis*, distinct from *P.wilcoxensis*. The specimens displaying this feature recorded herein are retained within *G.wilcoxensis*.

RANGE: Late Palaeocene to Middle Eocene (c.*G.pseudomenardii* Zone to *G.lehneri* Zone of Stainforth *et al.*, 1975; Zones P7 - ?P11 of Blow, 1979; Zones ?P5 - P12 of Blow, 1969 and Berggren & Van Couvering, 1974 in Toumarkine & Luterbacher, 1985).

According to Berggren (1960 & 1971) the first evolutionary occurrence of *G.wilcoxensis* lies within the *G.subbotinae* Zone and this level, the so-called "*Pseudohastigerina datum*" is used to define the base of the Eocene. However, Stainforth *et al.*, 1975 states that specimens indistinguishable from *G.wilcoxensis* have been observed from the *G.pseudomenardii* Zone in the eastern Mediterranean.

G.wilcoxensis has only been recorded from the Early Eocene in U.K. onshore sequences: from the London Clay (division E) of the London Basin and from the Bracklesham Group (various localities) of the Hampshire Basin (Murray *et al.*, 1989).

In the North Sea, *G.wilcoxensis* is recorded from the Early to basal Middle Eocene, Zones NSP5 - ?NSP7 (King, 1983). The lower limit of its range being difficult to define due to caving effects.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	common	**49/24-3**	abundant
29/25-1		**49/20-2**	mod. comm.	**49/24-4**	v.common
44/2-1		**49/24-2**	abundant	**49/25-2**	abundant
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily GLOBIGERINACEA Carpenter, Parker & Jones, 1862
Family GLOBIGERINIDAE Carpenter, Parker & Jones, 1862
Genus *Globigerina* d'Orbigny, 1826
***Globigerina chascanona* LOEBLICH & TAPPAN**
Recommended source for illustration:
Murray *et al.*(1989) pl.10.10, figs 1-3

1957 *Globigerina chascanona* LOEBLICH & TAPPAN

1960 *Globorotalia esnaensis* (Le Roy): BERGGREN, p.92, pl.10, fig.3 not pl.5, fig.3, not pl.6, fig.1

1989 *Globigerina chascanona* Loeblich & Tappan: MURRAY *et al.*, p.530, pl.10.10, figs 1-3

DIAGNOSIS: Test small, a tightly coiled moderate trochospire with 4.5 - 5 chambers in the final whorl increasing slowly in size. Surface pitted and spinose, especially on the umbilical side, aperture an umbilical arch with a thin lip

REMARKS: Murray *et al* (1989) state that this is a morphologically variable species which has also been recorded variously as *Globorotalia esnaensis* (Le Roy) and *Acarinina intermedia* Subbotina.

The illustration given by Murray *et al.* (1989), shows an apparent extraumbilical aperture which would transfer this taxon to *Globorotalia* and would reinforce the synonymous relationship between *G.chascanona* and *G.esnaensis*.

Berggren (1977) includes a variety of other forms in synonomy with his *G.esnaensis*, such as *Globigerina stonei* Weiss, *Globorotalia irrorata* Loeblich & Tappan, *Acarinina intermedia* Subbotina and *Globigerina whitei* Bolli. This possibly reflects the variable morphology demonstrated by *G.chascanona* herein.

Crittenden (1979 unpublished MS) however, has attempted to separate the various morphotypes within this group and has retained the majority of those taxa listed above.

RANGE: Late Palaeocene - Early Eocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	mod. comm.
29/25-1		**49/20-2**	rare	**49/24-4**	mod. comm.
44/2-1		**49/24-2**	mod. comm.	**49/25-2**	mod. comm.
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Globigerina eugubina LUTERBACHER & PREMOLI-SILVA / *G.fringa* SUBBOTINA "group"

Recommended source for illustration:
Toumarkine & Luterbacher (1985) figs 11.1-3,4-5

1950 *Globigerina fringa* SUBBOTINA p.104, pl.5, figs 19-21

1964 *Globigerina eugubina* LUTERBACHER & PREMOLI-SILVA p.105, pl.2, fig.8

1985 *Globigerina eugubina* Luterbacher & Premoli-Silva: TOUMARKINE & LUTERBACHER p.106, fig. 11.1-3

1985 *Globigerina fringa* Subbotina: TOUMARKINE & LUTERBACHER, p.106, Fig.11.4-5

DIAGNOSIS: Test extremely small, a low trochospire with 4 (fringa) - 6 (eugubina) subglobular chambers in the final whorl. Aperture extraumbilical, a low slit.

REMARKS: Many planktonic foraminiferal microfaunas in the earliest Palaeocene worldwide are dominated by extremely small species of less than 0.1mm size. Two forms; differing essentially in number of chambers, are recognised (e.g. by Toumarkine & Luterbacher, 1985). *G.fringa* (4 chambered version) is thought to be ancestral to *Morozovella pseudobulloides* and *G.eugubina* (5-6 chambered version) is thought to be ancestral to *Planorotalites compressa.* As Toumarkine & Luterbacher point out (1985, p.106) the generic positions of both taxa, particularly *G.eugubina*, are uncertain.

Specimens of very small planktonic foraminifera recorded from offshore material in this study are of very rare and are of very poor quality/preservation. Also, it is uncertain as to the exact stratigraphical position from where they were recorded as strata of earliest Danian age are extremely rare in the North Sea area. They may also be confused with juvenile forms of other Danian planktonic taxa. Therefore they are "grouped" together in this work.

RANGE: *G.eugubina* is restricted to the basal Danian, zone Pa - within subzone P1a whilst *G.fringa* ranges slightly higher, to the top of subzone P1b (Toumarkine & Luterbacher, 1985).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Globigerina patagonica TODD & KNIKER

Recommended source for illustration:
Murray *et al.* (1989) pl.10.10, figs 6-8, 10-12

1952 *Globigerina patagonica* TODD & KNIKER

1979 *Globigerina triangularis* White: CRITTENDEN p.74, pl.4 figs A-C

1989 *Globigerina patagonica* Todd & Kniker: MURRAY *et al.*, p.530, pl.10.10, figs 6-8, 10-12

DIAGNOSIS: Test a low trochospire with typically 3.5 chambers in the final whorl rapidly increasing in size, surface covered throughout with well-defined pore-pits, aperture an umbilical arch.

REMARKS: This species closely resembles *Globigerina triangularis* White as described by Crittenden (1979) from a North Sea well, which also has 3 - 3.5 chambers in the final whorl and is indeed regarded as synonymous with it. However, *G.triangularis sensu stricto* has been recorded from Late Palaeocene sediments elsewhere (Bolli, 1957).

S.triloculinoides (Palaeocene only) is very similar but tends to have somewhat larger pore-pits giving a distinct cancellate surface pattern, and a lower, distinctly lipped aperture.

RANGE: Early Eocene (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**	rare	**49/24-4**	rare
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Suborder ROTALIINA Delage & Herouard, 1896
Superfamily BOLIVINACEA Glaessner, 1937
Family BOLIVINIDAE Glaessner, 1937
Genus *Bolivina* d'Orbigny, 1839
***Bolivina incrassata* REUSS**
Recommended source for illustration:
Hart *et al.* (1989) pl. 7.4, figs 8-9

1851 *Bolivina incrassata* REUSS
1977 *Bolivina incrassata gigantea* Wicher: KOCH p.54, pl.14, figs 1-2
1977 *Bolivina incrassata crassa* Vasilenko & Myatliuk: KOCH p.54, pl.14, figs 3-4
1977 *Bolivina incrassata incrassata* Reuss: KOCH p.54, pl.14, figs 5-6
1989 *Bolivina incrassata* Reuss: HART *et al.* p.322, pl.7.4, figs 8-9

DIAGNOSIS: Test biserial elongate "blade-like", medium to large, varying in shape from long and slender to stout and robust. Test compressed, margins subrounded. Chambers are numerous and steeply inclined, sutures distinct though only slightly depressed. Aperture an elongate, wide, ovate subterminal opening.

REMARKS: Hart *et al.* (1989) describes this as a highly variable species whereas Koch (1977) has recognised three subspecies; *B.i.gigantea* (broad & large), *B.i.incrassata* (small) and *B.i.crassa* (elongate & slender). However, there appears to be little stratigraphic reason at least for this separation, which is not followed here.

RANGE: Late Campanian - Maastrichtian (Hart *et al.*,1989).

OCCURRENCE IN THIS WORK:

<table>
<tr><td colspan="6">OFFSHORE</td></tr>
<tr><td>21/26-1</td><td></td><td>49/10-1</td><td></td><td>49/24-3</td><td></td></tr>
<tr><td>29/25-1</td><td></td><td>49/20-2</td><td></td><td>49/24-4</td><td></td></tr>
<tr><td>44/2-1</td><td>mod.comm.</td><td>49/24-2</td><td></td><td>49/25-2</td><td>mod.comm.</td></tr>
<tr><td colspan="6">ONSHORE</td></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td></td></tr>
<tr><td colspan="2">Pegwell Bay</td><td></td><td colspan="2">Stevns Klint</td><td>rare</td></tr>
<tr><td colspan="2">Reculver</td><td>rare</td><td colspan="2"></td><td></td></tr>
</table>

Genus *Tappanina* Montanaro Gallitelli, 1955

Tappanina selmensis **(CUSHMAN)**

Recommended source for illustration:

Murray *et al.* (1989) pl.10.9, figs 14-15

1948 *Bolivinita selmensis* Cushman emend. Brotzen: BROTZEN p.56 pl.9 fig.7

1986 *Tappanina selmensis* (Cushman): van MORKHOVEN *et al.*, p.332 pl.108

1989 *Tappanina selmensis* (Cushman): MURRAY *et al.*, p.528, pl.10.9 figs14-15

DIAGNOSIS: Biserial, tapering, rhomboid in cross section, broad chamber faces that are distinctly concave, sutures distinct, periphery acute.

REMARKS: Van Morkhoven *et al.* (1986) regard *T.selmensis* as an outer neritic - bathyal dweller. However, Murray *et al.* (1989) record the species from the Reculver Silts of the Thanet Formation in Kent which were deposited under much shallower conditions although in a transgressive setting.

RANGE: Recorded worldwide from the Maastrichtian - Early Eocene (Van Morkhoven *et al.*, 1986) although only recorded from the Late Palaeocene of the U.K. It approaches its full stratigraphical range (Maastrichtian - Palaeocene) in Sweden (Brotzen, 1948).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	?	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**	rare	**49/25-2**	
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		mod. comm.
Reculver					

Family BOLIVINOIDIDAE Loeblich & Tappan, 1984

Genus *Bolivinoides* Cushman, 1927

Bolivinoides draco **(MARSSON)**

Recommended source for illustration:

Hart *et al.* (1989) pl. 7.4, fig.13

1878 *Bolivina draco* MARSSON

1989 *Bolivinoides draco* (Marsson): HART *et al.*, p.324, pl.7.4, fig.13

DIAGNOSIS: Test free, rhomboidal, compressed, margins subacute to acute, often carinae. Initial end bluntly rounded followed by 6-7 pairs of biserially arranged chambers. Test surface covered by strongly developed, longitudinally elongated lobes, four on each chamber, which coalesce to form longitudinal ribs. Aperture wide, loop shape, bordered by a thin lip and possessing an internal tooth-plate.

REMARKS: The two inner-most ribs are continuous and run parallel to the median line and is characteristic of this species

RANGE: Latest Early - Late Maastrichtian (Hart *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	rare
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	rare

ONSHORE			
Wormingford Mere		**Lundsgaards Cliff**	
Pegwell Bay		**Stevns Klint**	
Reculver			

Bolivinoides laevigatus MARIE

Recommended source for illustration:
Hart *et al.* (1989) pl. 7.5, figs 1-2

1941 *Bolivinoides laevigatus* MARIE
1989 *Bolivinoides laevigatus* Marie: HART *et al.* p.324, pl.7.5, figs 1-2

DIAGNOSIS: Test free, elongate, compressed with a subacute periphery. A globular proloculus followed by 7-9 pairs of distinct, biserial chambers with slightly depressed sutures. Test surface possesses weakly developed circular to elongate nodes (c.2-3 per chamber). Aperture narrow and looped shaped.

REMARKS: The relatively weak ornamentation helps to distinguish this species from others in the genus.

RANGE: Late Campanian - Early Maastrichtian (Hart *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	?
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver		rare			

Bolivinoides miliaris HILTERMANN & KOCH

Recommended source for illustration:
Hart *et al.* (1989) pl. 7.5, fig.3

1950 *Bolivinoides miliaris* HILTERMANN & KOCH

1989 *Bolivinoides miliaris* Hiltermann & Koch: HART *et al.* p.324, pl.7.5, fig.3

DIAGNOSIS: Test free, kite-shaped, compressed with acute margins. Proloculus globular followed by 7-8 pairs of slightly inflated biserial chambers with indistinct sutures except at the periphery. Test surface initially pustulose, later possessing elongate narrow lobes (c.3 per chamber). Aperture loop shaped occasionally bordered by an indistinct lip.

REMARKS: This species' gross morphology is similar to that of *B.draco* although it lacks the twin central parallel ribs characteristic of *B.draco*.

RANGE: Latest Campanian - Early Maastrichtian (Hart *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Bolivinoides paleocenicus (BROTZEN)

Recommended source for illustration:
Hart *et al.* (1989) pl. 7.5, fig.4

1948 *Bolivina paleocenica* BROTZEN
1989 *Bolivinoides paleocenicus* Brotzen: HART *et al.*, p.324, pl.7.5, fig.4

DIAGNOSIS: Test free, kite-shaped, compressed with a subacute periphery. Initial proloculus followed by 6-7 pairs of uninflated biserial chambers. Sutures distinct near the periphery but obscured in the centre of the test by a raised network of intersecting narrow ridges. Aperture narrow and loop shaped.

REMARKS: The surface sculpture of this species is distinctive.

RANGE: Later Early Maastrichtian (Hart *et al.*, 1989) - Palaeocene (Brotzen, 1948).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	?	**49/24-2**		**49/25-2**	

ONSHORE			
Wormingford Mere		**Lundsgaards Cliff**	
Pegwell Bay		**Stevns Klint**	rare
Reculver			

Superfamily EOUVIGERINACEA Cushman, 1927
Family EOUVIGERINIDAE Cushman, 1927
Genus *Eouvigerina* Cushman, 1926

Eouvigerina aculeata (EHRENBERG)

Recommended source for illustration:
Hart *et al.* (1989) pl. 7.8, figs 3-4

1854 *Loxostomum aculeata* EHRENBERG
1989 *Eouvigerina aculeata* (Ehrenberg): HART *et al.*, p.330, pl.7.8, figs 3,4

DIAGNOSIS: Test free, small, biserial with rounded margins, chambers slightly pyriform, final chamber centrally positioned, sutures convex, somewhat “flanged”, aperture terminal on a short neck.

REMARKS: This small species is fairly distinctive, though occurs in very low numbers within Chalk sections of this study. Somewhat similar is the Late Palaeocene species *Tappanina selmensis*, which has concave chamber faces and a basal aperture.

RANGE: Hart *et al.*, 1989 indicates that this species ranges from the Coniacian to the early Maastrichtian although also notes that the uncertain taxonomic status of this species somewhat devalues its stratigraphical value.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		mod. comm.
Reculver		rare			

Genus *Loxostomum* (Cushman, 1926)
***Loxostomum eleyi* (CUSHMAN)**
Recommended source for illustration:
Hart *et al.* (1989) pl. 7.19 , figs 4,5

1927 *Bolivinita eleyi* CUSHMAN
1989 *Loxostomum eleyi* (Cushman): HART *et al.*, p.352, pl.7.19, figs 4-5

DIAGNOSIS: Test free, elongate, compressed, biserial with a truncated edge. Chambers flat, overlapping and reniform in outline. Sutures distinct, flush to slightly raised and curved. Aperture terminal, an ovoid slit surrounded by a slightly raised lip.

REMARKS: This is a fairly distinctive species which Hart *et al.* (1989) records as being widespread over Europe.

RANGE: Santonian - Middle Campanian, very rare in the Late Campanian (Hart *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		49/10-1		49/24-3	
29/25-1		49/20-2		49/24-4	
44/2-1		49/24-2		49/25-2	
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily TURRILINACEA Cushman, 1927
Family TURILINIDAE Cushman, 1927
Genus *Praebulimina* Hofker, 1953
***Praebulimina laevis* (BEISSEL)**
Recommended source for illustration:
Hart *et al.* (1989) pl. 7.21, figs 1-2

1891 *Bulimina laevis* BEISSEL
1989 *Praebulimina laevis* (Beissel): HART *et al.* p.356, pl.7.21, figs 1-2

DIAGNOSIS: Test free, subfusiform and large. Initial end rounded then flaring rapidly with 3-4 chambers in the final whorl. Chambers slightly inflated with flush to slightly depressed sutures. Aperture comma-shaped within the apertural face, occasionally bordered by a thin lip.

REMARKS: This species is fairly consistently recorded in Maastrichtian age sediments around the NW European area.

RANGE: Latest Campanian - Maastrichtian (Hart *et al.* 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		49/10-1		49/24-3	rare
29/25-1	rare	49/20-2		49/24-4	
44/2-1	rare	49/24-2		49/25-2	common
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		mod. comm.
Reculver					

Genus *Turrilina* Andreae, 1884

***Turrilina brevispira* TEN DAM**

Recommended source for illustration:

King (1989) pl.9.8, fig.22

1944 *Turrilina brevispira* TEN DAM

1989 *Turrilina brevispira* Ten Dam: KING, p.482, pl.9.8, fig.22

DIAGNOSIS: Test free, rather small and fusiform in overall shape, a high trochospire composed of inflated chambers with 3 in the final whorl which in itself comprises about two-thirds of the total test volume. The characteristic aperture is a broad, slit-like opening along the base of the apertural face of the final chamber.

REMARKS: This species differs from similar *Bulimina* spp. by the characteristic basal slit-like aperture.

RANGE: Early (-?Middle & Late) Eocene (King, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	rare	**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1	?	**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily BULIMINACEA Jones, 1875

Family BULIMINIDAE Jones, 1875

Genus *Bulimina* d'Orbigny, 1826

***Bulimina aksuatica* MOROZOVA**

Recommended source for illustration:

King (1989) pl.9.5, fig.1

1939 *Bulimina truncana* var. *aksuatica* Morozova

1989 *Bulimina aksuatica* Morozova: KING p.468 pl.9.5 fig.1

DIAGNOSIS: Test free, small, tapering with a triangular cross section, sutures somewhat obscured by fine, numerous, longitudinal, uninterrupted ribs.

REMARKS: This species is fairly distinguishable by its small size and its numerous longitudinal ribs.

RANGE: Early - Late Eocene (King, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1	rare	**49/24-2**	rare	**49/25-2**	mod. comm.
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Bulimina midwayensis CUSHMAN & PARKER

Recommended source for illustration:
King (1989) pl.9.5, fig.6

1936 *Bulimina arkadelphiana var. midwayensis* CUSHMAN & PARKER p.42 pl.7 figs.9-10

1948 *Bulimina midwayensis* Cushman & Parker: BROTZEN p.58 pl.10 fig.8

1966 *Bulimina midwayensis* Cushman & Parker: HOFKER p.335 pl.81 figs.129, 134, 136, 138-9, 142-3, 151

1970 *Bulimina midwayensis* Cushman & Parker: HANSEN p.64 pl.7 figs.1-2 pl.18, figs 5-6

1975 *Bulimina midwayensis* Cushman & Parker: BERGGREN & AUBERT p.145 pl.II fig.5 pl.XIV fig.8 pl.XVII fig.1 pl.XIX fig.7

1983 *Bulimina midwayensis* Cushman & Parker: TJALSMA & LOHMAN p.6 pl.3 fig.1

1989 *Bulimina midwayensis* Cushman & Parker: KING p.470, pl.9.5, fig.6

DIAGNOSIS: Test free, fairly large, chambers increasing in size rapidly, triangular in profile with rounded cross-section, lower part of chambers have weak ribs which tend to overhang the chamber margins.

REMARKS: This is a geographically widespread Palaeocene index species first described from the Midway Formation of the United States. It is similar to the Early Eocene form *Bulimina* sp.*A* of King (1989) from which it differs in being more tapering.

Tjalsma & Lohman (1983) have recorded this species from a wide bathymmetric range in the Palaeocene of the Atlantic Ocean.

RANGE: Late Palaeocene (King, 1989; Berggren & Aubert, 1975; and others).

OCCURRENCE IN THIS WORK:

<table>
<tr><td colspan="6">OFFSHORE</td></tr>
<tr><td>21/26-1</td><td></td><td>49/10-1</td><td></td><td>49/24-3</td><td></td></tr>
<tr><td>29/25-1</td><td></td><td>49/20-2</td><td></td><td>49/24-4</td><td></td></tr>
<tr><td>44/2-1</td><td>rare</td><td>49/24-2</td><td>rare</td><td>49/25-2</td><td>rare</td></tr>
<tr><td colspan="6">ONSHORE</td></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td>rare</td></tr>
<tr><td colspan="2">Pegwell Bay</td><td></td><td colspan="2">Stevns Klint</td><td></td></tr>
<tr><td colspan="2">Reculver</td><td></td><td colspan="2"></td><td></td></tr>
</table>

Bulimina trigonalis TEN DAM

Recommended source for illustration:
King (1989) pl.9.5, fig.7

1944 *Bulimina trigonalis* TEN DAM
1948 *Bulimina paleocenica* BROTZEN p.61, pl.6, figs 5-6
1989 *Bulimina thanetensis* Cushman & Parker: MURRAY *et al.*, p.515, pl.10.3, figs 24-25
1989 *Bulimina trigonalis* Ten Dam: KING p.470, pl.9.5, fig.7

DIAGNOSIS: Test free, relatively small, smooth, elongated, trigonal cross-section in early part, becoming more rounded with moderately inflated chambers, test often slightly twisted.

REMARKS: This species is distinguished from other *Bulimina* spp. by its lack of ornamentation although in borehole ditch cuttings samples it may be confused with other similar species caved from higher stratigraphic levels such as *B.gibba* (Early Pliocene - Recent) and *B.elongata* (Late Oligocene - early Late Miocene).

Various names have been applied to small elongate Palaeocene buliminids. Murray *et al.*, 1989 states that *B.thanetensis* is larger than *B.trigonalis*. *B.simplex* Ten Dam has a quadrangular aperture, *B.paleocenica* Brotzen is more sharply triangular and *B.rosenkrantzi* Brotzen has an enlarged final whorl. It may be that these taxa are ecological variants.

This species is recorded (as *B.thanetensis*) from the Thanet Formation of Kent (Murray *et al.*, 1989) where it is thought to be indicative of marginal marine to mid-shelf depths and probably tolerant of muddy substrates with reduced oxygen levels.

A form very similar to this species has been recorded from the Late Cretaceous interval in well 49/25-2. It has been recorded as *B.?trigonalis* on charts.

RANGE: Late Palaeocene (King, 1989; Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	?	**49/10-1**	rare	**49/24-3**	rare
29/25-1		**49/20-2**	rare	**49/24-4**	
44/2-1	rare	**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		mod. comm.
Pegwell Bay		abundant	**Stevns Klint**		
Reculver		rare			

Bulimina sp.*A* KING

Recommended source for illustration:
King (1989) pl.9.5, fig.9

1983 *Bulimina* sp. nov. KING
1989 *Bulimina* sp.*A* King: KING p.470, pl.9.5, fig.9

DIAGNOSIS: Test free, fairly large, chambers increasing in size fairly slowly, rounded cross-section, lower part of chambers overhang previous chambers and have relatively strong ribs which tend to overhang the chamber margins.

REMARKS: Differs from *B.midwayensis* by its less tapering (i.e. less triangular) test and more robust marginal ribs.

RANGE: Early Eocene (King, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	mod. comm.	**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Family UVIGERINIDAE Haeckel, 1894

Genus *Uvigerina* d'Orbigny, 1826

***Uvigerina batjesi* KAASSCHIETER**

Recommended source for illustration:

Murray *et al.* (1989) pl. 10.9, figs 19-20

1961 *Uvigerina batjesi* KAASSCHIETER

1989 *Uvigerina batjesi* Kaasschieter: KING, p.484, pl.9.9, fig.5

1989 *Uvigerina batjesi* Kaasschieter: MURRAY *et al.* p.528, pl.10.9, figs. 19-20

DIAGNOSIS: Test initially triserial, becoming uniserial. Almost circular cross-section with inflated chambers and depressed sutures in the later part. Test surface finely hispid. Aperture terminal with a slight neck and lip.

REMARKS: *U.farinosa* is similar but is more elongate and more densely ornamented.

Murray *et al.* (1989) indicate this species can be found from slightly brackish to middle shelf environments with muddy substrates.

RANGE: Early Eocene (King, 1989 and Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Uvigerina eocaena GUEMBEL

Recommended source for illustration:
King (1989) pl. 9.9, fig.6

1870 *Uvigerina eocaena* GUEMBEL

1989 *Uvigerina eocaena* Guembel: KING p.484, pl.9., fig.6

DIAGNOSIS: Test large, short with rapidly expanding chambers. Sutures indistinct with a few (2-4 per chamber) thick longitudinal ribs partly crossing sutures.

REMARKS:

RANGE: Middle? - Late Eocene (King, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Uvigerina farinosa HANTKEN

Recommended source for illustration:
King (1989) pl. 9.7, fig. 7

1875 *Uvigerina farinosa* HANTKEN
1989 *Uvigerina farinosa* Hantken: KING p.484, pl.9.9, fig.7

DIAGNOSIS: Test small, elongated, initially triserial but tending to become bi/uniserial. Chambers moderately inflated and densely ornamented by tiny blunt spines. Aperture terminal with a long neck

REMARKS: This species tends to be more elongate and more densely ornamented than *U.batjesi*.

RANGE: Middle - Late Eocene in the North Sea area (King, 1989) but has a longer range (Early Eocene - Late Oligocene in oceanic areas (Boersma, 1984).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere		**Lundsgaards Cliff**			
Pegwell Bay		**Stevns Klint**			
Reculver					

Uvigerina germanica (CUSHMAN & EDWARDS)

Recommended source for illustration:
Murray *et al.* (1989) pl. 10.9, figs 21-22

1938 *Angulogerina germanica* CUSHMAN & EDWARDS
1989 *Uvigerina germanica* (Cushman & Edwards): KING p.482, pl.9.9, fig.4
1989 *Uvigerina germanica* (Cushman & Edwards): MURRAY *et al.* p.528, pl.10.9, figs 21-22

DIAGNOSIS: Test triserial becoming uniserial, roughly circular (King, 1989) to triangular (Murray *et al.*, 1989) in cross section. Chambers inflated, earlier ones ornamented by

longitudinal costae, later ones smooth (Murray *et al.*, 1989) or faintly spinose (King, 1989). Aperture terminal, large, elliptical with a lip.

REMARKS: Despite the rather different diagnostic elements put forward for this species by King, 1989 and Murray *et al.*, 1989, the presence of costae on the earlier chambers is distinctive and helps separation of this species from other members of the genus. Murray *et al.* (1989) also indicate that this species' palaeoecology is normal marine, shelf, and on a muddy substrate.

RANGE: King (1989) and Murray *et al.* (1989) also quote two separate stratigraphic ranges for this species: Late Eocene - basal Early Oligocene and Middle Oligocene respectively.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Uvigerina tenuipustulata VAN VOORTHUYSEN

Recommended source for illustration:

King (1989) pl. 9.9, fig. 12

1950 *Uvigerina tenuipustulata* VAN VOORTHUYSEN

1989 *Uvigerina tenuipustulata* Van Voorthuysen: KING p.484, pl.9.9, fig.12

DIAGNOSIS: Test small, triserial - later biserial, elongated. Chambers inflated and ornamented by numerous very small, short, blunt spines.

REMARKS: This spinose species is similar to *U.batjesi* and *U.farinosa,* though stratigraphically distinct. However, the other two species tend to become uniserial in the later growth stages unlike this species which tends to remain tri/bi serial throughout.

RANGE: Early - Middle Miocene (King, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Family REUSSELLIDAE Cushman, 1933

Genus *Reussella* Galloway, 1933

***Reussella szajnochae szajnochae* (GRZYBOWSKI)**

Recommended source for illustration:
Hart *et al.* (1989) pl. 7.22, fig.8

1896 *Verneuilina szajnochae* GRZYBOWSKI
1989 *Reussella szajnochae szajnochae* (Grzybowski): HART *et al.* p.360, pl.7.22, fig.8

DIAGNOSIS: Test free, triserial throughout and triangular with sharp, serrated and spinose test margins. Sutures distinct, raised and carinate, projecting from the test angles to form downward pointing spines. Aperture a slit-like opening, extending up the apertural face and bordered by a distinct lip.

REMARKS: This is a very distinctive species which is important biostratigraphically in offshore Chalk sections. It can be locally abundant within some zones of the Late Maastrichtian and forms a useful guide fossil for horizontal drilling in certain Late Cretaceous chalk reservoirs.

RANGE: This species has a rather unusual stratigraphic distribution in that it first occurs in the Late Campanian with an apparent gap before re-appearing in the Late Maastrichtian.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**	rare	
Reculver					

Superfamily STILOSTOMELLACEA Finlay, 1947
Family STILOSTOMELLIDAE Finlay, 1947
Genus *Stilostomella* Guppy, 1894
***Stilostomella subspinosa* (CUSHMAN)**
Recommended source for illustration:
Tjalsma & Lohmann (1983) pl. 14, figs 16-17

1943 *Ellipsonodosaria subspinosa* CUSHMAN p.92, pl.16, figs 6-7b

1983 *Stilostomella subspinosa* (Cushman): TJALSMA & LOHMANN .36, pl.14, figs 16-17

DIAGNOSIS: Test free, elongate, uniserial, about 6-9 inflated, barrel-shaped chambers with distinct, depressed sutures. Surface delicately but densely spinose with spines tending to coalesce into fine costae in the early part of the test. Aperture terminal, produced on a short neck and bordered by a flange-like lip.

REMARKS:

RANGE: Late Eocene - Miocene (?and younger). Rarer in the Middle Eocene (Tjalsma & Lohmann, 1983).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		49/10-1		49/24-3	
29/25-1		49/20-2		49/24-4	
44/2-1		49/24-2		49/25-2	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily DISCORBACEA Ehrenberg, 1838
Family EPONIDIDAE Hofker, 1951
Genus *Neoeponides* de Montfort, 1808
***Neoeponides karsteni* (REUSS)**
Recommended source for illustration:
King (1989) p.479, pl.9.7, figs 27-28

1855 *Rotalia karsteni* REUSS
1989 *Neoeponides karsteni* (Reuss): KING p.479, pl.9.7, figs 27-28

DIAGNOSIS: Test biconvex, compressed with a subacute periphery and a thin keel, up to three whorls visible on spiral side with 5-6 chambers in the final whorl. Sutures strongly oblique, umbilical sutures radial, deepening somewhat towards the umbilicus to produce lobate chamber ends. Surface distinctly perforate except over sutures.

REMARKS: An easily distinguished species, the spiral side sutures (imperforate) being very distinctive.

RANGE: Middle Eocene (King, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare

ONSHORE			
Wormingford Mere		**Lundsgaards Cliff**	
Pegwell Bay		**Stevns Klint**	
Reculver			

Family ROSALINIDAE Reiss, 1963

Genus *Rosalina* d'Orbigny, 1826

Rosalina binkhorsti **REUSS**

Recommended source for illustration:

Koch (1977) pl. 6, figs 8-9

1862 *Rosalina binkhorsti* REUSS p.317, pl.2, fig.3

1950 *Gavelinella binkhorsti* (Reuss): VISSER p.265, pl.5, fig.6

1966 *Mississippina binkhorsti* (Reuss): HOFKER p.138, pl.20, figs 44,46

1977 *Rosalina binkhorsti* Reuss: KOCH p.66, pl.6, figs 8-9

DIAGNOSIS: Test small, a low trochospire with a flat to somewhat concave umbilical side and a lobate periphery. Chambers slightly inflated, increasing fairly rapidly in size. Sutures broad and distinct, raising above the chamber surface on the dorsal side leading to a somewhat "excavated" chamber surface.

REMARKS: A distinctive species with the characteristic "excavated" dorsal chamber surfaces.

RANGE: Late Maastrichtian - Danian (Koch, 1977).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Rosalina squamiformis sensu HOFKER (non REUSS)

Recommended source for illustration:
Hofker (1966) pl. 20, fig. 34

?1845 Genus unknown *squamiformis* REUSS (cited by Hofker, 1966)
1950 *Rosalina squamiformis* (Reuss): VISSER p.261, pl.5, fig.1
1966 *Neoconorbina squamiformis* (Reuss): HOFKER p.139, pl.20, fig.34

DIAGNOSIS: Test a low, conical trochospire with a concave umbilical side and an almost circular, non-lobate periphery. About 4-5 lunate chambers with the final chamber occupying approximately one-third on the whole test from the umbilical side. Early whorls visible on the dorsal side. Sutures fairly broad, distinct and strongly recurved. Aperture a low slit covered by a flap.

REMARKS: Hofker (1966) is uncertain about the exact affinity of his species, described from the Maastrichtian Chalk, and states Reuss's original species was actually first described from the Turonian. The present author could not, however, trace any reference to a species designated as *squamiformis* by Reuss. Hofker indicates that his specimens may represent a different, though morphologically similar taxon.

RANGE: Turonian? - Maastrichtian (Hofker, 1966) though recorded in the Danian in this study.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		rare
Reculver					

Family SPHAEROIDINIDAE Cushman, 1927

Genus *Sphaeroidina* d'Orbigny, 1826

Sphaeroidina bulloides

Recommended source for illustration:

Van Moorkhoven *et al.* (1986) pl. 24

1826 *Sphaeroidina bulloides* D'ORBIGNY p.267

1986 *Sphaeroidina bulloides* d'Orbigny: VAN MOORKHOVEN *et al.* p.80, pl.24

DIAGNOSIS: Test subglobular, generally 3 to occasionally 4 rapidly enlarging chambers, the final chamber comprising c.50% of the test. Test wall smooth, sutures fairly distinct. Aperture a semicircular arch which occurs on the umbilical side at or near the junction between the final three chambers.

REMARKS: Van Moorkhoven *et al.* (1986) regards this species as occurring commonly at middle and upper bathyal depths, with markedly reduced numbers up to middle shelf depths.

RANGE: Early Oligocene - Pleistocene (Van Moorkhoven *et al.* 1986).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**	rare	**49/25-2**	
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Family SIPHONINIDAE Cushman, 1927

Genus *Pulsiphonina* Brotzen, 1948

***Pulsiphonina prima* (PLUMMER)**

Recommended source for illustration:

Murray *et al.* (1989) pl. 10.9, figs 5-7

1927 *Siphonina prima* PLUMMER

1989 *Pulsiphonina prima* (Plummer): MURRAY *et al.*, p.526, pl.10.9,figs 5-7

DIAGNOSIS: A compressed, biconvex, low trochospire with an acute periphery. 4-5 chambers in the final whorl. Numerous relatively coarse perforations, particularly located along sutures and around the periphery. Aperture a low arch close to the periphery.

REMARKS: This species is fairly distinctive and lacks the frilled keel of the similar Oligo-Miocene taxon *Siphonina reticulata*. Murray *et al.*, 1989 state that this species is found on mainly muddy substrates in slightly brackish - normal marine, inner shelf waters.

RANGE: Late Palaeocene - Early Eocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**		**49/25-2**	mod. comm.
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Siphonina* Reuss

***Siphonina reticulata* CZJZEK**

Recommended source for illustration:

King (1989) pl. 9.8, fig. 17

1848 *Siphonina reticulata* CZJZEK

1850 *Siphonina fimbriata* REUSS

1989 *Siphonina reticulata* Czjzek: KING p.482, pl.9.8, fig.17

DIAGNOSIS: Test flattened biconvex, a very low trochospire with approximately 5 chambers in the final whorl, with a characteristic "frilled" periphery and ovate aperture protruding normally on a short neck.

REMARKS: A distinctive Oligo-Miocene species which differs from the related Palaeocene - Eocene species *Pulsiphonina prima* (Plummer) by the frilled periphery and protruding aperture. It occurs fairly commonly in well 49/24-2 which suggests heavy contamination of Early Palaeogene samples from caving above.

RANGE: Late Oligocene - Middle Miocene (King, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	rare	**49/24-3**	mod. comm.
29/25-1		**49/20-2**	rare	**49/24-4**	rare
44/2-1		**49/24-2**	common	**49/25-2**	mod. comm.
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily DISCORBINELLACEA Sigal, 1952
Family PARRELLOIDIDAE Hofker, 1956
Genus *Cibicidoides* Thalmann, 1939
***Cibicidoides alleni* (PLUMMER)**
Recommended source for illustration:
Murray *et al.* (1989) pl. 10.5, figs 13-15

1927 *Truncatulina alleni* PLUMMER

1948 *Cibicidoides proprius* BROTZEN p.78 pl.12 figs.3-4

1975 *Cibicidoides alleni* (Plummer):BERGGREN & AUBERT p.151 pl.V fig.1a-d pl.VII figs.1a-3d pl.IX fig.5 pl.X fig.1 pl.XI fig.11 pl.XIV fig.2 pl.XV fig.11 pl.XVIII fig.1 pl.XIX fig.5

1976 *Cibicidoides alleni* (Plummer): AUBERT & BERGGREN p.431 pl.10 fig.2

1983 *Cibicides proprius* (Brotzen):DOPPERT & NEELE pl.XI fig.2, pl.XV fig.2, pl.XXII fig.1

1989 *Cibicidoides alleni* (Plummer):MURRAY *et al.* p.518 pl.10.5 figs.13-15

DIAGNOSIS: Test a biconvex, low trochospire. Early part of spiral side somewhat low conical, periphery subacute, umbilicus shallow. 8-11 chambers in the final whorl, sutures recurved on the spiral side, radial becoming moderately recurved on the umbilical side. Aperture a peripheral arch which extends slightly onto the spiral side. Wall coarsely perforate.

REMARKS: Berggren & Aubert (1975) have discussed an extensive synonomy of *C.alleni* and suggest that this species has a high degree of variability. They note that it has been recorded from many localities worldwide and is a characteristic component of middle shelf (30-100m) palaeodepths from circum-Atlantic and Mediterranean (Tethyan) areas.

C.pygmaeus is similar but is a more inflated biconvex form.

Murray *et al.* (1989) includes *C.proprius* (Brotzen) within *C.alleni* and indicates that this species lives on various substrates in brackish to normal marine, inner to mid-shelf conditions.

This species has been recorded from the London Basin (Thanet Beds and London Clay), the Hampshire Basin (London Clay, Barton & Bracklesham Groups), the Paris basin (Thanetian & Lutetian) and the Belgian Basin (Ypresian - Paniselian) (Murray *et al.*, 1989). Aubert & Berggren (1976) regard this form as one of the principal components of the Palaeocene benthic assemblage in their study of Tunisia.

RANGE: Worldwide: Late Palaeocene - Early Eocene (authors above).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		rare
Pegwell Bay		rare	**Stevns Klint**		
Reculver		rare			

Cibicidoides dayi (WHITE)

Recommended source for illustration:

King (1989) pl.9.5, figs 25-26

1928 *Planulina dayi* WHITE
1976 *Cibicidoides dayi* (White): AUBERT & BERGGREN p.431 pl.10 fig.3
1986 *Cibicidoides dayi* (White): van MORKHOVEN *et al.* p.353, pl.114
1989 *Cibicidoides dayi* (White): KING p.471 pl.9.5 figs.25-26.

DIAGNOSIS: Test compressed and thinly biconvex, a very low trochospire almost planispiral with a subacute periphery. 12-17 chambers in the final whorl. Spiral side finely perforate and covered with raised ridges near prominent umbonal area, umbilical side smooth and mainly imperforate.

REMARKS: Van Morkhoven *et al.* (1986) contains an extensive discussion of this species' taxonomy. *C.dayi* is similar to *Planularia costata* but is trochospiral and has more chambers in the final whorl. They also remark that the prominent spiral side umbo is rarely visible in deep water forms of this species.

RANGE: North Sea Basin: Late Cretaceous - Late Palaeocene (King, 1989). Worldwide Late Cretaceous - Late Palaeocene (van Morkhoven, 1986).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Cibicidoides eocaenus (GUEMBEL)

Recommended source for illustration:
King (1989) pl. 9.6, figs 1-2

1868 *Rotalia eocaena* GUEMBEL
1928 *Cibicides tuxpamensis* COLE
1932 *Cibicides perlucida* NUTTALL
1983 *Cibicidoides tuxpamensis* (Cole):TJALSMA & LOHMANN p.28 pl.18 figs.3-4 pl.22 figs.1-3
1986 *Cibicidoides eocaenus* (Guembel): van MORKHOVEN *et al.* p.256, pls 86A-D
1989 *Cibicidoides eocaenus* (Guembel): KING p.472 pl.9.6 figs.1-2.

DIAGNOSIS: Test almost planoconvex with a very inflated and subconical umbilical side with the spiral side only slightly convex. 9-10 chambers in the final whorl with an evolute spiral side. Periphery acute to subrounded. Wall is coarsely perforate except for a non-perforate spiral suture. A large glassy knob covering the umbilicus may be present. Aperture a low arch which extends from the mid point of the base of the apertural face to very slightly onto the spiral side.

REMARKS: Van Morkhoven *et al.* (1986) extensively discusses the taxonomy of this species and retains the name *'eocaenus'* for the plexus of species including *C.perlucidus* (Nutall) and *C.tuxpamensis* Tjalsma & Lohmann, which characterise type of periphery (angular and rounded respectively). Tjalsma & Lohmann (1983) record this species (as *C.tuxpamensis*) from a wide range of palaeobathymmetries in the Palaeogene of Atlantic Ocean sites, but with highest frequencies at shallower sites (1000m-2000m).

RANGE: North Sea Basin: Early - Late Eocene (King, 1989). Worldwide Early Eocene - Late Oligocene (van Morkhoven *et al.*, 1986).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Cibicidoides ex gr. ***dutemplei*** **(D'ORBIGNY)**

Recommended source for illustration:

Van Moorkhoven *et al.* (1986) pl. 35

1846 *Rotalina dutemplei* D'ORBIGNY, p.157, pl.8, figs 19-21

1986 *Cibicidoides dutemplei* (d'Orbigny): VAN MOORKHOVEN p.112, pl.35

1989 *Cibicidoides dutemplei peelensis* (Ten Dam & Reinhold): KING p.472, pl.9.6, figs 3-4

1989 *Cibicidoides mexicanus* (Nuttall): KING p.472, pl.9.5, figs 27-29

DIAGNOSIS: Test free, variable between almost biconvex to planoconvex, although umbilical side is always more convex than the spiral side. Approximately 8 chambers in the

final whorl with approximately 2½ - 3 whorls visible on the dorsal side. Sutures curved on spiral and straight on umbilical side, generally flush, distinguished as imperforate bands.

REMARKS: Specimens recorded in this study have been "lumped" into this taxonomical grouping as their occurrences in the samples are probably due to the result of caving. However, King (1989) generally follows Van Moorkhoven (1986) who distinguishes between biconvex forms (forma *peelensis*) and planoconvex forms (forma *praecincta* or *mexicanus*). The forms appear to be characteristic of neritic/upper bathyal and middle/lower bathyal environments respectively.

RANGE: Oligocene - Pliocene (King, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	mod. comm.	**49/24-3**	rare
29/25-1		**49/20-2**	rare	**49/24-4**	rare
44/2-1	mod. comm.	**49/24-2**	rare	**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Cibicidoides pachyderma (RZEHAK)

Recommended source for illustration:
King (1989) pl.9.5, figs 22-24

1846 *Rotalina ungeriana* d'ORBIGNY
1886 *Truncatulina pachyderma* RZEHAK p.87, pl.1 fig.5a-c
1922 *Truncatulina pseudoungerianus* CUSHMAN pl.4 figs.15-16,22
1941 *Cibicides pseudoungerianus* (Cushman): DAM & REINHOLD, p.62 pl.5 fig.4a-c
1980 *Heterolepa pseudoungerianus* (Cushman): DOPPERT pl.11 fig.1
1983 *Cibicidoides ungerianus* (d'Orbigny):TJALSMA & LOHMANN p.28 pl.18 fig.1 pl.21 figs.5-6
1989 *Cibicidoides pachyderma* (Rzehak): KING p.472 pl.9:5 figs.22-24
not 1989 *Cibicides cf. ungerianus* (d'Orbigny):MURRAY *et al.* p.518 pl.10.5 figs.7-9

DIAGNOSIS: Test a biconvex, lenticular low trochospire with an acute to subacute periphery. 10-12 chambers in the final whorl with early whorls indistinct. Spiral side coarsely perforate, finely perforate umbilical side with a somewhat swollen umbilical area.

Aperture a low arch confined to just around the periphery and extending backwards along the spiral suture.

REMARKS: There appears to be some slight confusion in various taxonomies between *C.pseudoungerianus* (Cushman) and *C.ungerianus* (d'Orbigny) and their relationship (if any) to *C.pachyderma* (Rzehak). *C.ungerianus* (d'Orbigny) is, according to the description and figures in Murray *et al.* (1989), a thin lenticular biconvex species with an acute, sometimes keeled periphery. *C.pseudoungerianus* (Cushman) is a more inflated biconvex form which King (1989) regards as synonymous with *C.pachyderma* (Rzehak). The illustration of *C.pachyderma* (King, 1989 pl.9.5 figs.22-24) show this taxon as being an inflated biconvex form. Both King (1989) and Murray *et al.* (1989) regard these forms as Neogene in age.

Murray *et al.* (1989) describe and illustrate a form referred to as *Cibicides cf. ungerianus* within which they include d'Orbigny's type species *Rotalina ungeriana*. However, whilst noting that "Eocene forms have a more rounded periphery than forms from the Neogene" (p.518), their illustration shows a specimen with almost subglobular inflated chambers and a very well rounded periphery which would perhaps be better compared with *Cibicides cassivelauni* Haynes, or *Cibicides cunobelini* Haynes.

Tjalsma & Lohmann (1983) record *Cibicidoides ungerianus* (d'Orbigny) from deep water Palaeogene sediments from the Atlantic Ocean and state that it ranges from the Early Eocene into the Oligocene and has a wide bathymmetric range.

Murray *et al.* (1989) also compare and contrast the morphology of *C.pseudoungerianus* (which they do not describe or illustrate) with the Eocene species *Cibicides lobatulus* (Walker & Jacob).

Clearly, there appears to be some disagreement between authors over the concept and nomenclature of this taxon or taxonomic group. In this study, the name *Cibicidoides pachyderma* (Rzehak) is retained (following King, 1989) and is used for forms with wide lenticular biconvex morphologies.

In this instance *C.pachyderma* is broadly similar morphologically to *Cibicidoides alleni* (Plummer) although tends to have a rather "fatter" lenticular profile and a slightly higher number of chambers in the final whorl. However, to add further apparent confusion, the form illustrated as *C.alleni* by Aubert & Berggren (1976) from Tunisia (Pl.10 fig.2), appears to have a rather "fat" lenticular profile and only a moderately convex spiral side.

Cibicidoides pygmeus (Hantken) also has a relatively high degree of inflated biconvexity although has fewer chambers in the final whorl and an aperture which does not extend onto the spiral side.

Lack of sufficient numbers and the uncertainty of precise stratigraphic control in the samples analysed for this study prevents a solution to the problem being proposed here. Certainly Palaeogene cibicidiids and their allies are an abundant and diverse group within the shallow water Palaeogene sediments in and around the margins of the (mainly) Southern North Sea Basin. Their offshore subsurface distribution needs much further work.

RANGE: Worldwide: Early Eocene - Miocene (sources from authors above).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	?	**49/24-3**	rare
29/25-1	?	**49/20-2**		**49/24-4**	
44/2-1	?	**49/24-2**	rare	**49/25-2**	?
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Cibicidoides pygmeus (HANTKEN)

Recommended source for illustration:
Murray *et al.* (1989) pl.10.5, figs 16-17

1875 *Pulvinulina pygmea* HANTKEN
1983 *Cibicides pygmeus* (Hantken): DOPPERT & NEELE pl.VIII fig.1
1989 *Cibicidoides pygmeus* (Hantken): MURRAY *et al.* p.518 pl.10.5 figs.16-18.

DIAGNOSIS: Test a rather "fat" lenticular trochospire with a subacute periphery. 8-10 chambers in the final whorl with an evolute spiral side and an involute umbilical side. Wall coarsely perforate. Aperture a low slit extending from near the umbilicus to the periphery but not onto the spiral side.

REMARKS: Murray *et al.* (1989) records this species from the Eocene of the Hampshire Basin (Bracklesham & Barton Groups and London Clay) and Belgian Basin but not from the London or Paris Basins. They regard it as an inner to middle shelf dweller.

Doppert & Neele (1983) have recorded this species from the Palaeogene of the Dutch onshore.

RANGE: U.K. onshore: Early - Late Eocene (Murray *et al.*, 1989). Dutch onshore: Early Eocene - Oligocene (Doppert & Neele, 1983).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Cibicidoides succedens (BROTZEN)

Recommended source for illustration:
King (1989) pl.9.6, figs 5-6

1948 *Cibicides succedens* BROTZEN p.60 pl.12 fig.1
1975 *Cibicidoides succedens* (Brotzen): BERGGREN & AUBERT p.154 pl.XIV fig.5
1976 *Cibicidoides succedens* (Brotzen): AUBERT & BERGGREN p.432 pl.11 fig.1
1989 *Cibicidoides succedens* (Brotzen): KING p.474 pl.9.6 figs.5-6
1989 *Cibicides (Cibicidina) succedens* Brotzen: MURRAY *et al.* p.518 pl.10.5 figs.1-3

DIAGNOSIS: Test planoconvex to slightly biconvex with an almost flat spiral side. Umbilical side strongly convex, occasionally swelling into a prominent central boss. Periphery subacute to acute and may be keeled. 8-10 chambers in the final whorl. Sutures limbate, raised and strongly curved on the spiral side, slightly curved on umbilical side. Aperture a small opening at the base of the apertural face, near the periphery extending very slightly onto the spiral side. Wall very finely perforate.

REMARKS: *Cibicides westi* Howe, is very similar although the aperture extends well onto the spiral side and follows the spiral suture. The spiral side is also completely flat. It also has a different stratigraphic range (Middle - Late Eocene) to *C.succedens*.

Cibicides tenellus (Reuss) is also similar although the umbilical side displays a much more broadly rounded convexity and there are slightly more chambers in the final whorl. *Cibicides cantii* Haynes, has fewer chambers in the final whorl.

Berggren & Aubert (1975) record this species from the Palaeocene - Early Eocene of Rockall Bank (N.Atlantic), southern Scandinavia, Poland and the southwestern area of the former Soviet Union. They also include an extensive synonomy list.

King (1989) has recorded this species from the North Sea Basin. Murray *et al.* (1989) have recorded *C.succedens* from the Thanet Beds of the London Basin and the Paris Basin but not from the Belgian or Hampshire Basins. They regard it as a marginal marine to mid-shelf dweller, possibly tolerant of a poorly aerated mud bottom.

This species forms the principal component of the Palaeocene benthonic assemblages of Tunisia (Aubert & Berggren, 1976).

RANGE: U.K. and North Sea Basin: Late Palaeocene (King, 1989, Murray *et al.*, 1989). Worldwide: Palaeocene - Early Eocene (Berggren & Aubert, 1975).

OCCURRENCE IN THIS WORK:

<table>
<tr><td colspan="6">OFFSHORE</td></tr>
<tr><td>21/26-1</td><td></td><td>49/10-1</td><td>rare</td><td>49/24-3</td><td>?</td></tr>
<tr><td>29/25-1</td><td></td><td>49/20-2</td><td>?</td><td>49/24-4</td><td>mod. comm.</td></tr>
<tr><td>44/2-1</td><td></td><td>49/24-2</td><td></td><td>49/25-2</td><td></td></tr>
<tr><td colspan="6">ONSHORE</td></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td>mod. comm.</td></tr>
<tr><td colspan="2">Pegwell Bay</td><td>mod. comm.</td><td colspan="2">Stevns Klint</td><td></td></tr>
<tr><td colspan="2">Reculver</td><td>mod. comm.</td><td colspan="2"></td><td></td></tr>
</table>

Cibicidoides susanaensis (BROWNING)

Recommended source for illustration:
Aubert & Berggren (1976) pl.11, fig. 2a-c

1959 *Cibicides susanaensis* BROWNING p.271, pl.32, figs 11-12

1976 *Cibicidoides susanaensis* (Browning): AUBERT & BERGGREN p.432, pl.11, fig. 2a-c

DIAGNOSIS: Test almost equally biconvex and almost planispiral with 11-12 chambers increasing slowly in size, sutures raised, thick and strongly recurved, apertural face also

curved. Central portion thick though umbilicus is relatively wide and deep. Intersutural areas distinctly perforate. Periphery subangular and "blunt". Aperture a low arch at the base of the apertural face.

REMARKS: The almost planispiral test and thickened sutural ribs are distinctive. This species was recorded by Aubert & Berggren (1976) from Tunisian Palaeocene assemblages although they stated it is particularly abundant in deeper deposits. In this study it has only been recorded in well 49/25-2, within a shallow water assemblage.

RANGE: Late Cretaceous - Early Eocene (Aubert & Berggren, 1976).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Cibicidoides truncanus (GUEMBEL)

Recommended source for illustration:
King (1989) pl.9.6, fig.7

1869 *Rotalia truncana* GUEMBEL

1983 *Cibicidoides granulosus* (Bykova): KING p.33, pl.5 figs 7-8

1986 *Cibicidoides truncanus* (Guembel): van MORKHOVEN *et al.* p.295, pls 97A-B

1989 *Cibicidoides truncanus* (Guembel): KING p.474 pl.9.6 fig.7

DIAGNOSIS: Test a biconvex trochospire with the umbilical side more convex than the spiral side. 9-10 chambers in the final whorl. Periphery is acute and may have a broad, "frilled" keel. The wall is coarsely perforate and the umbilical side is covered by an ornament of raised ridges often forming a "rosette-like" pattern.

REMARKS: In gross appearance, this taxon resembles *Osangularia* although is referred to *Cibicidoides* by Van Morkhoven *et al.* (1986) who have discussed the taxonomy of this species in detail. It is distinguished by the ornament pattern on the umbilical side. King

(1989) has recorded this species (and as *C.granulosus* in 1983) from the outer sublittoral - epibathyal biofacies of the North Sea Basin.

RANGE: A worldwide Middle - Late Eocene index species (van Morkhoven *et al.*, 1986).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	?
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1	rare	**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily PLANORBULINACEA Schwager, 1877

Family PLANULINIDAE Bermudez, 1952

Genus *Planulina* d'Orbigny, 1826

Planulina costata (HANTKEN)

Recommended source for illustration:

King (1989) pl.9.8, figs 12-13

1875 *Truncatulina costata* HANTKEN

1941 *Planulina palmerae* van BELLEN

1983 *Planulina palmerae* van Bellen: KING pl.4 figs.17-18,23

1983 *Planulina burlingtonensis* (Jennings): DOPPERT & NEELE pl.XIV fig.1

1986 *Planulina costata* (Hantken): van MORKHOVEN *et al.* p.212, pl.72

1989 *Planulina costata* (Hantken): KING p.480 pl.9.8 figs.12-13

DIAGNOSIS: Test very compressed, evolute, almost flattened and almost planispiral. 10-12 chambers in the final whorl with earlier whorls visible. Sutures limbate and strongly curved, periphery acute and keeled.

REMARKS: An easily distinguishable compressed planispiral species. *Anomalinoides acuta* (Plummer) is less compressed and with a less acute and unkeeled periphery. *Cibicidoides susanaensis* is almost planispiral and less compressed, more lenticular. Van Morkhoven *et al.* (1986) regard this as a mainly mid-upper bathyal species although ranging from outer neritic (c.100m) - lower bathyal water depths overall.

RANGE: North Sea: Late Eocene - (rarely) Early Oligocene (King, 1989). Worldwide: Late Eocene - Early Miocene (all sources above).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	?
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Family CIBICIDIDAE Cushman, 1927

Genus *Cibicides* de Montfort, 1808

***Cibicides beaumontianus* (D'ORBIGNY)**

Recommended source for illustration:

Hart *et al.* (1989) pl. 7.5, figs 9-10

1840 *Truncatulina beaumontiana* D'ORBIGNY

1989 *Cibicides beaumontianus* (d'Orbigny): HART *et al.*, p.326, pl.7.5, figs 9-10

DIAGNOSIS: Test plano-convex, shape variable, margins distinctly rounded, chambers distinct, subglobular, 5-6 in the final whorl. Sutures distinct, depressed and straight. Wall smooth to very slightly rugose on the ventral side. Aperture an equatorial slit to semicircular hole, extending back along the dorsal side following the spiral suture.

REMARKS: This attached form has considerable morphological variation, especially along the dorsal side along which the attachment is made (Hart *et al.*, 1989).

RANGE: Santonian - Maastrichtian (Hart *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	?	**49/24-3**	?
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		rare
Reculver					

Cibicides cantii HAYNES

Recommended source for illustration:
Murray *et al.* (1989) pl. 10.4, figs 5-7

1957 *Cibicides cantii* HAYNES

1989 *Cibicides cantii* Haynes: MURRAY *et al.* p.516 pl.10.4 figs.5-7

DIAGNOSIS: Test a plano-convex trochospire with an acute periphery. 6-8 chambers in the final whorl, chambers initially lobate, becoming arcuate. Spiral side coarsely perforate. Aperture a low peripheral arch which extends onto the spiral side and back along the spiral suture.

REMARKS: This species is similar to *C.succedens* and *Cibicides westi* Howe, although posses fewer chambers in the final whorl than them both (6-8 cf.8-10).

Murray *et al.* (1989) record this species from the Thanet Beds of the London Basin but give no record for it's occurrence in the Hampshire, Paris or Belgian Basins. It is thought to be indicative of normal marine, ?brackish, inner shelf palaeoenvironments.

RANGE: U.K. onshore: Late Palaeocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		mod. comm.	**Stevns Klint**		
Reculver		common			

Cibicides cassivelauni **HAYNES**

Recommended source for illustration:

Murray *et al.* (1989) pl. 10.4, figs 8-10

1957 *Cibicides cassivelauni* HAYNES

1989 *Cibicides cassivelauni* Haynes: MURRAY *et al.* p.516 pl.10.4 figs.8-10

DIAGNOSIS: Test a planoconvex, low trochospire with a flattened spiral side and a subacute periphery. Umbilical side only moderately convex. 7-8 chambers in the final whorl, coarsely perforate on the spiral side but only the last few are perforate on the umbilical side. Aperture a low peripheral arch, extending onto the spiral side although only running a short way back along the spiral suture.

REMARKS: *Cibicides lobatulus* (Walker & Jacob) is similar in shape but has large pores covering all the umbilical side. *Cibicides tenellus* (Reuss) has more chambers and a higher degree of convexity on the umbilical side.

Murray *et al.* (1989) record this species from the Thanet Beds of the London Basin but not from the Hampshire, Paris or Belgian Basins. It is regarded as a normal marine, inner to mid-shelf dweller.

RANGE: U.K. onshore: Late Palaeocene (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	?

ONSHORE			
Wormingford Mere		**Lundsgaards Cliff**	
Pegwell Bay	mod. comm.	**Stevns Klint**	
Reculver	common		

Cibicides cunobelini HAYNES

Recommended source for illustration:
Murray *et al.* (1989) pl. 10.4, figs 11-13

1957 *Cibicides cunobelini* HAYNES

1989 *Cibicides (Cibicidina) cunobelini* Haynes: MURRAY *et al.* p.516 pl.10.4 figs.11-13

DIAGNOSIS: Test a very low biconvex trochospire with the umbilical side occasionally more convex than the spiral side. Periphery subrounded. 7-10 chambers in the final whorl with limbate sutures on the spiral side which swell into small bosses towards the umbilicus. In later chambers these are replaced by lappets along the base of the last few chambers. The aperture is a low peripheral arch which extends onto the spiral side.

REMARKS: *Cibicides mariae* (Jones) has more well developed lappets and has a concave spiral side.

Murray *et al.* (1989) record this species from the Thanet Beds of the London Basin, the London Clay of the Hampshire Basin and the Thanetian-Sparnacian and Cuisian of the Paris Basin. They do not record it from the Belgian Basin.

Murray *et al.* (1989) consider this species to be a brackish - normal marine, inner shelf dweller which lives on fine grained sediment substrates.

RANGE: N.W. onshore Europe: Late Palaeocene - Early Eocene (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	?
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		mod. comm.	**Stevns Klint**		
Reculver		abundant			

Cibicides lobatulus (WALKER & JACOB)

Recommended source for illustration:
Murray *et al.* (1989) pl. 10.4, figs 14-16

1798 *Nautilus lobatulus* WALKER & JACOB

1989 *Cibicides lobatulus* (Walker & Jacob):MURRAY *et al.* p.516 pl.10.4 figs.14-16

DIAGNOSIS: Test plano or concavo-convex with the spiral side flat and evolute. 7-9 chambers in the final whorl. Periphery acute. The aperture is a low peripheral arch which extends back along the spiral suture for 3-4 chambers. The spiral side is finely perforate, the umbilical side appears imperforate and smooth.

REMARKS: *C.lobatulus* is close to the morphology of *C.cantii* which has coarser pores on the spiral side, slightly fewer chambers and a somewhat less smooth and inflated umbilical side. *C.pachyderma* (=*C.pseudoungerianus*) has a more convex spiral side.

This is an extant species which lives clinging or attached to firm substrates such as shells. It has been recorded by Murray *et al.* (1989) from the Reading Beds of the London Basin, the London Clay, Bracklesham and Barton Groups of the Hampshire Basin, the Thanetian - Sannoisian of the Paris Basin and the Ypresian - Rupelian of the Belgian Basin.

Murray *et al.* (1989) indicate this species as inhabiting a marine inner to middle shelf palaeoenvironment often in areas disturbed by currents.

RANGE: U.K. onshore: Early - Late Eocene and Recent (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		mod. comm.	**Stevns Klint**		
Reculver					

Cibicides mariae (JONES)

Recommended source for illustration:

Murray *et al.* (1989) pl. 10.4, figs 17-19

1852	*Rosalina mariae* JONES
1948	*Anomalina ekblomi* BROTZEN p.82 pl.13 fig.2
1957	*Cibicidina mariae* (Jones): WOOD & HAYNES p.51 pl.5 figs.10,12 pl.6 fig.4
1975	*Cibicidina mariae* (Jones): BERGGREN & AUBERT p.146
1989	*Cibicides (Cibicidina) mariae* (Jones):MURRAY *et al.* p.516 pl.10.4 figs.17-19

DIAGNOSIS: Test concavo-convex and involute with the spiral side concave. 8-9 chambers in the outer whorl. Sutures limbate on spiral side with well developed lappets towards the umbilical area. Aperture is a low peripheral arch which extends onto the spiral side. The surface is finely perforate.

REMARKS: This species differs from *C.cunobelini* by the presence of well developed sutural lappets and by being truly concavo-convex.

Murray *et al.* (1989) record this species from the Thanet and Reading Beds of the London Basin but not from the Hampshire, Paris or Belgian Basins. The species inhabits normal marine, inner shelf and possibly brackish palaeoenvironments. Berggren & Aubert (1975) state that this species generally inhabits water depths of less than 50m.

Berggren & Aubert (1975) regard this species as an important constituent of their so-called "Midway type" Palaeocene benthic assemblages. They provide an extensive synonomy and include the Swedish and Danish taxon *Anomalina ekblomi* (Brotzen) within *C.mariae* (following the suggestion of McGowran, 1965).

RANGE: U.K. onshore: Late Palaeocene (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		49/10-1		49/24-3	
29/25-1		49/20-2		49/24-4	
44/2-1		49/24-2		49/25-2	
ONSHORE					
Wormingford Mere			Lundsgaards Cliff		
Pegwell Bay		mod. comm.	Stevns Klint		
Reculver		abundant			

Cibicides cf. simplex BROTZEN

Recommended source for illustration:
Murray *et al.* (1989) pl. 10.4, figs 20-22

1948 *Cibicides simplex* BROTZEN

1989 *Cibicides cf. simplex* Brotzen: MURRAY *et al.* p.516 pl.10.4 figs.20-22

DIAGNOSIS: Test a rather "plump" mainly involute plano - bi-convex trochospire with a well rounded periphery. 6-10 chambers in the final whorl. Aperture a low peripheral arch which extends back along the spiral suture. The surface appears to be finely, but densely perforate.

REMARKS: This species is distinguished by it's broadly rounded, wide profile. Murray *et al.* (1989) recorded this species from the London Clay of the Hampshire basin but not from the London, Paris or Belgian Basins. It is thought to inhabit brackish, inner shelf muddy sand substrates.

RANGE: U.K. onshore: Early Eocene (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		49/10-1		49/24-3	
29/25-1		49/20-2		49/24-4	rare
44/2-1		49/24-2		49/25-2	rare
ONSHORE					
Wormingford Mere			Lundsgaards Cliff		
Pegwell Bay			Stevns Klint		
Reculver					

Cibicides tenellus (REUSS)

Recommended source for illustration:
Murray *et al.* (1989) pl. 10.5, figs 4-6

1865 *Truncatulina tenella* REUSS
1980 *Cibicides tenellus* (Reuss): DOPPERT pl.XVIII, fig.4
1989 *Cibicides tenellus* (Reuss): MURRAY *et al.* p.518 pl.10.5 figs.4-6

DIAGNOSIS: Test a planoconvex trochospire with a flat and evolute spiral side and a strongly convex, involute umbilical side. 8-12 chambers in the final whorl. Periphery acute, sutures wide and recurved on the spiral side, depressed and slightly curved on the umbilical side. Aperture is a low peripheral arch which extends back along the spiral suture. The spiral side appears finely but densely perforate whereas the umbilical side appears perforate only near the periphery.

REMARKS: *C.cantii* and *Cibicides westi* Howe, have a more "conical" umbilical sides when compared with *C.tenellus* and have slightly fewer chambers. *C.cassivelauni* and *C.lobatulus* have lower and less inflated umbilical sides and fewer chambers.

Murray *et al.* (1989) records *C.tenellus* from the Bracklesham and Barton Groups of the Hampshire Basin, the Auversian - Marinesian of the Paris Basin and the Ledian - Tongrian of the Belgian Basin. However, Doppert (1980) recorded this species only from the Middle Miocene - mid Oligocene of onshore Holland.

RANGE: U.K. onshore: Early - Late Eocene (Murray *et al.*, 1989). Dutch onshore: mid Oligocene - Middle Miocene (Doppert, 1980).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	rare
29/25-1		**49/20-2**	?	**49/24-4**	rare
44/2-1		**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Cibicides cf. ungerianus (d'ORBIGNY)

Recommended source for illustration:
Murray *et al.* (1989) pl. 10.5, figs 7-9

1846 *Rotalina ungeriana* d'ORBIGNY
1983 *Cibicides ungerianus* (d'Orbigny): DOPPERT & NEELE pl.III fig.3
1989 *Cibicides cf. ungeriamus* (d'Orbigny):MURRAY *et al.* p.518 pl.10.5 figs.7-9

DIAGNOSIS: Test an unequally biconvex trochospire with the spiral side only slightly convex and partly involute. The early part of the spiral side is thickened with bosses. Umbilical side convex and involute. 8-11 chambers in the outer whorl, periphery rounded. Aperture is a low peripheral arch which extends back along the spiral suture. Wall coarsely perforate.

REMARKS: This species' morphology does not appear to be comparable with *C.ungerianus sensu stricto* (=*C.pachyderma* herein) although this taxon is distinct enough to recognise this form as taxonomically different from that species. For simplicity, the name assigned by Murray *et al.* (1989) i.e. *C.* "cf." *ungeriamus* is retained here.

The taxon is distinguished by the thickening of the early portion of the test by bosses on the spiral side.

Murray *et al.* (1989) record this taxon from the Bracklesham and Barton Groups of the Hampshire Basin, the Marinesian of the Paris Basin and the Paniselian -Rupelian of the Belgian Basin but not from the London Basin. It inhabits a normal marine, inner or mid-shelf palaeoenvironment.

RANGE: U.K. onshore: Middle - Late Eocene (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1	rare	**49/24-2**		**49/25-2**	rare

ONSHORE			
Wormingford Mere		**Lundsgaards Cliff**	
Pegwell Bay		**Stevns Klint**	
Reculver			

Cibicides westi HOWE

Recommended source for illustration:
Murray *et al.* (1989) pl. 10.5, figs 10-12

1939 *Cibicides westi* HOWE
1983 *Cibicidoides westi* (Howe): TJALSMA & LOHMAN p.29
1983 *Cibicides westi* Howe: DOPPERT & NEELE pl.XIV fig.2
1989 *Cibicides westi* Howe: MURRAY *et al.* p.518 pl.10.5 figs.10-12

DIAGNOSIS: Test planoconvex with a flat evolute spiral side and a strongly convex, almost conical involute umbilical side. Periphery is acute. Aperture is a small low peripheral arch which extends back along the spiral suture. The spiral side contains scattered pores whereas the umbilical side appears imperforate.

REMARKS: *C.tenellus* has more pores on both spiral and umbilical sides. *C.succedens* has a slightly raised spiral side and *C.cantii* has fewer chambers and has a lower conical umbilical side.

Murray *et al.* (1989) has recorded *C.westi* from the London Clay of the London Basin, the Barton Group of the Hampshire Basin, the Ypresian - Bartonian of the Paris Basin and the Ypresian - Wemmelian of the Belgian Basin.

Doppert & Neele (1983) have recorded it from the Early - Middle Eocene of onshore Holland and Tjalsma & Lohman (1983) state that it has been rarely recorded from the Eocene of the North Atlantic.

RANGE: NW Europe onshore: Eocene (Murray *et al.*, 1989 and Doppert & Neele, 1983). Atlantic: Eocene (Tjalsma & Lohmann, 1983).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare

ONSHORE			
Wormingford Mere		**Lundsgaards Cliff**	
Pegwell Bay		**Stevns Klint**	
Reculver			

Superfamily ASTERIGERINACEA d'Orbigny, 1839
Family ASTERIGERINIDAE d'Orbigny, 1839
Genus *Asterigerina* d'Orbigny, 1839
***Asterigerina aberystwythi* HAYNES**
Recommended source for illustration:
Murray *et al.* (1989) pl.10.3 figs 9-11

1956 *Asterigerina aberystwythi* HAYNES p.97, pl.17, fig.6
1989 *Asterigerina aberystwythi* Haynes: MURRAY *et al.*, p.514, pl.10.3, figs 9-11

DIAGNOSIS: Test small, a bi- or planoconvex trochospire with a flattened umbilical side, 4-5 chambers per whorl, approximately three whorls visible on spiral side, small supplementary chamberlets visible on the umbilical side, periphery very acute, aperture a low arch at base of apertural face.

REMARKS: The only species of *Asterigerina* recorded in this study. It can, however, be distinguished from the common Eocene species *A.bartoniana* (Ten Dam) by its smaller size, fewer chambers and flattened umbilical side.

RANGE: Late Palaeocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	?	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Superfamily NONIONACEA Schultze, 1854
Family NONIONIDAE Schultze, 1854
Genus *Melonis* de Montfort, 1808
***Melonis pompillioides* (FICHTEL & MOLL)**
Recommended source for illustration:
Van Moorkhoven *et al.* (1986) pls. 23A-E

1798 *Nautilus pompillioides* FICHTEL & MOLL, p.31, pl.2 figs a-c

1846 *Melonis soldanii* D'ORBIGNY p.109, pl.5, figs 15-16

1958 *Melonis sphaeroides* VOLOSHINOVA p.153, pl.3, figs 8-9

1986 *Melonis pompillioides* (Fichtel & Moll): VAN MOORKHOVEN *et al.*, p.72, pls.23A-E

1989 *Melonis affine* (Reuss): MURRAY *et al.*, p.522, pl.10.7, figs 12-13

DIAGNOSIS: Test planispiral, involute, varying in overall shape between compressed and subspherical, biumbilicate. Periphery rounded. Approximately 10 chambers in the final whorl. Aperture an interiomarginal arch.

REMARKS: Van Moorkhoven *et al.* (1986) extensively discusses the synonomy of this taxon and its palaeoenvironmental significance. He recognises that the morphological variation between relatively compressed forms (e.g. *M.affine* of authors) through "mildly inflated" forms (e.g. *M.soldanii* of authors) to subspherical forms (e.g. *M.sphaeroides* of authors) is due to bathymetrically controlled factors rather than the forms being distinct taxa. He states that *M.pompillioides* is essentially an outer neritic to upper-middle bathyal species with its deeper-water ecotype, *M.sphaeroides* being a reliable indicator for abyssal depths.

Murray *et al.* (1989) on the other hand, regards *M.affine* as an inner to mid shelf species.

The forms recorded in this study were of the *M.affine-M.soldanii* ecotypes with no records of the subspherical *M.sphaeroides* ecotype.

RANGE: Late Oligocene - Pleistocene (Van Moorkhoven *et al.*, 1989). However, Murray *et al.* (1989) records *M.affine* in the Middle - Late Eocene.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	rare	**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	mod.comm.	**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Nonion* de Montfort, 1808

Nonion applinae HOWE & WALLACE

Recommended source for illustration:
Murray *et al.* (1989) pl. 10.7, figs 15-16

1932 *Nonion applinae* HOWE & WALLACE p.51, pl.9, fig.4
1956 *Nonion applinae* Howe & Wallace: HAYNES p.85, pl.16, fig.7, pl.18, fig.4
1989 *Nonion applinae* Howe & Wallace: MURRAY *et al.*, p.522, pl.10.7 figs 15-16

DIAGNOSIS: Test planispiral, involute, compressed, periphery rounded, 7-9 chambers in the final whorl, sutures radial, depressed, umbilical area small and granulate, aperture a low slit at base of a high apertural face.

REMARKS: This species is more compressed than other *Nonion* species. It is similar to *Anomalinoides nobilis* and *Melonis soldanii* but can be distinguished by the depressed sutures and granular umbilicus. Murray *et al.* (1989) indicate that this is shallow marine species, possibly tolerant of brackish waters.

RANGE: Late Palaeocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay	rare		**Stevns Klint**		
Reculver	rare				

Nonion laeve (d'ORBIGNY)

Recommended source for illustration:
Murray *et al.* (1989) pl. 10.7, figs 17-18

1826 *Nonionina laeve* d'ORBIGNY p.294, no.11
1956 *Nonion laeve* (d'Orbigny): HAYNES p.86, pl.16, fig.10
1989 *Nonion laeve* (d'Orbigny): MURRAY *et al.*, p.522, pl.10.7, figs 17-18

<u>**DIAGNOSIS**</u>: Test planispiral, involute, compressed with a subangular periphery, 10-14 chambers in the final whorl, umbilicus covered with a boss, sutures radial to slightly curved and occasionally deeply depressed and ornamented with tubercles.

<u>**REMARKS**</u>: Murray *et al.* (1989) indicate that this is a variable taxon with respect to chamber numbers, degree of suture depression and size of umbilical boss. They regard it as a brackish to normal marine, shallow water species.

<u>**RANGE**</u>: Late Palaeocene - Early Oligocene (Murray *et al.*, 1989).

<u>**OCCURRENCE IN THIS WORK**</u>:

<table>
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<tr><td>29/25-1</td><td></td><td>49/20-2</td><td></td><td>49/24-4</td><td></td></tr>
<tr><td>44/2-1</td><td></td><td>49/24-2</td><td></td><td>49/25-2</td><td>?</td></tr>
<tr><td colspan="6">ONSHORE</td></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td></td></tr>
<tr><td colspan="2">Pegwell Bay</td><td>rare</td><td colspan="2">Stevns Klint</td><td></td></tr>
<tr><td colspan="2">Reculver</td><td>rare</td><td colspan="2"></td><td></td></tr>
</table>

Genus *Pullenia* Parker & Jones, 1862

Pullenia quaternaria

Recommended source for illustration:

Hart *et al.* (1989) pl. 7.22, fig.3

1851 *Nonionina quaternaria* REUSS

1989 *Pullenia quaternaria* (Reuss): HART *et al.*, p.358, pl.7.22, fig.3

<u>**DIAGNOSIS**</u>: Test planispiral, subglobular involute coil with 4-5 chambers in the final whorl. Outline subcircular to weakly lobate, chambers triangular, sutures curved and flush to weakly depressed. Aperture a low interiomarginal slit, bordered by a thick imperforate band.

<u>**REMARKS**</u>: This taxon appears to be overall more rounded that *P.quinqueloba* and the sutures are generally more curved.

<u>**RANGE**</u>: Middle Campanian - Maastrichtian (Hart *et al.* 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		rare
Reculver					

***Pullenia quinqueloba* (REUSS)**

Recommended source for illustration:

Murray *et al.* (1989) pl. 10.9, figs 3-4

1851 *Nonionina quinqueloba* REUSS

1989 *Pullenia quinqueloba* (Reuss): MURRAY *et al.*, p.526, pl.10.9, figs 3-4

DIAGNOSIS: Planispiral, involute, somewhat compressed, with a subrounded periphery, occasionally subspherical with a well rounded periphery. 5-6 chambers in the final whorl, wall smooth, somewhat "glassy".

REMARKS: This species is somewhat similar to certain Palaeogene *Nonion* spp., (particularly *N.parvulum*) but lacks the pustulose ornament around the aperture.

P.quaternaria has fewer chambers and is generally more well rounded in overall shape

Subspherical forms may perhaps be referred to *P.bulloides*. However, the present author considers that the variation in overall test shape from somewhat compressed (*P.quinqueloba* of authors) to subspherical *P.bulloides* of authors) *may* be due to some sort of bathymetrically-controlled ecological variation in the same way as the *Melonis pompillioides* "group".

RANGE: Late Palaeocene - Early Eocene (Murray *et al.*, 1989)

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	rare	**49/24-3**	mod. comm.
29/25-1		**49/20-2**		**49/24-4**	mod. comm.
44/2-1	mod. comm.	**49/24-2**	mod. comm.	**49/25-2**	mod. comm.
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		mod. comm.
Pegwell Bay		rare	**Stevns Klint**		rare
Reculver		mod. comm.			

Superfamily CHILOSTOMELLACEA Brady, 1881
Family QUADRIMORPHINIDAE Saidova, 1981
Genus *Quadrimorphina* Finlay, 1939
***Quadrimorphina allomorphinoides* (REUSS)**
Recommended source for illustration:
Swiecicki (1980) pl. 14, figs 6-7

1850 *Allomorphina allomorphinoides* REUSS
1980 *Quadrimorphina allomorphinoides* (Reuss): SWIECICKI pl.14, figs 6-7
1983 *Allomorphina trigona* Reuss: DOPPERT & NEELE pl.XXIII, fig.5

DIAGNOSIS: Test free, medium sized, a low trochospire (almost "globigerine") of 3-4 fairly rapidly enlarging chambers, the last chamber occupying approximately one-third to one-half of the final whorl. Aperture is umbilical though often covered by a large flap extending from the final chamber. Periphery lobate, wall very smooth.

REMARKS: This distinctive species is often recorded in the Maureen Formation within an interval often associated with intense reworking of Late Cretaceous / Danian taxa. It's non-chalk preservation, however, suggests that it is probably *in situ* at this level.

There does not appear to be a significant morphological or stratigraphic difference between this species and *Allomorphina trigona* Reuss as illustrated from the Late Palaeocene, Landen Formation by Doppert & Neele (1983).

RANGE: Late Cretaceous - lower Late Palaeocene (Swiecicki, 1980 and this study).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere		**Lundsgaards Cliff**			
Pegwell Bay		**Stevns Klint**	rare		
Reculver					

Family ALABAMINIDAE Hofker, 1951

Genus *Alabamina* Toulmin, 1941

***Alabamina obtusa* (BURROWS & HOLLAND)**

Recommended source for illustration:

Murray *et al.* (1989) pl.10.2, figs 19-21

1897 *Pulvinulina exigua* Brady var. *obtusa* BURROWS & HOLLAND p.49, pl.2, fig.25

1926 *Pulvinulina exigua* Brady: PLUMMER p.151 pl.11 fig.3 (and var. *obtusa* Burrows & Holland p.150 pl.11 fig.2)

1948 *Alabamina midwayensis* BROTZEN p.99 pl.16 figs.1-2 text figs.25-26

1956 *Alabamina obtusa* (Burrows & Holland): HAYNES p.89, pl.17 figs. 3-31

1975 *Alabamina midwayensis* Brotzen: BERGGREN & AUBERT p.147 pl.II fig.14 pl.XII fig.2

1976 *Alabamina obtusa* (Burrows & Holland): AUBERT & BERGGREN p.429 pl.8 fig.4 not *A.midwayensis* Brotzen p.428 pl.8 fig.3

1968 *Alabamina midwayensis* Brotzen: POZARYSKA & SZCZECHURA p.114 text fig.20

?1983 *Alabamina creta* (Finlay): TJALSMA & LOHMANN p.4 pl.7 fig.13

1983 *Alabamina midwayensis* Brotzen: DOPPERT & NEELE pl.XXIII fig.3

1989 *Alabamina obtusa* (Burrows & Holland):MURRAY *et al.* p.512 pl.10.2 figs.19-21

DIAGNOSIS: Test smooth, unequally biconvex with the umbilical side more highly convex than the spiral side. Generally 5 chambers in the final whorl and a subrounded periphery. Sutures on spiral side flush, straight and pointing backwards, approximately tangential to the spiral suture. Sutures on umbilical side radial and flush, umbilicus closed. Aperture is a high, fairly narrow slit which extends into an infolded apertural face.

REMARKS: *A.solnasensis* has more inflated chambers, depressed sutures and an altogether more inflated, rounded appearance with a lobate periphery.

Haynes (1956) first indicated the synonomy between *A.obtusa*, first recorded from the Thanet Beds of Kent by Burrows & Holland (1897) and the more widely reported *A.midwayensis*. *A.obtusa* clearly has priority over the latter name as followed by Murray *et al.* (1989) and this author.

The form illustrated as *A.midwayensis* by Aubert & Berggren (1976) from the Palaeocene of Tunisia (pl.8 fig.3) has a subacute to acute periphery and would be perhaps best referred to *Alabamina westraliensis* Toulmin.

A.obtusa appears to be common in "Midway type" assemblages worldwide (Brotzen, 1948; Berggren & Aubert, 1975). Tjalsma & Lohmann (1983) do not record it from deeper water "Velasco type" assemblages in the Palaeocene Atlantic. Instead, they record *Alabamina creta* (Finlay) in rare numbers from the Caribbean and Falklands Plateau. Their illustration (pl.7 fig.13) however, appears to be very similar to the form illustrated by Doppert & Neele (1983) as *A.midwayensis* (*A.obtusa* herein) (pl.XXIII fig.3) although *A.creta* seems to have 4½ rather than 5 chambers in the final whorl. It is suggested here that *A.creta* may be a deep water morphotype of *A.obtusa* although more study would be needed to clarify this.

Alabamina obtusa has been recorded (Murray *et al.*, 1989) from the London Clay of the Hampshire Basin, the Thanet & Reading Beds and the London Clay of the London Basin, the Thanetian and Cuisian of the Paris Basin and the Thanetian and Ypresian of the Belgian Basin. It is thought to occur in slightly brackish, inner shelf waters on muddy substrates. King (1989) does not record any species of *Alabamina* from the Palaeocene and Eocene of the North Sea.

RANGE: Worldwide: Palaeocene - Early Eocene. NW Europe onshore: Late Palaeocene - Early Eocene.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	rare
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere		**Lundsgaards Cliff**	rare		
Pegwell Bay	rare	**Stevns Klint**			
Reculver					

Alabamina solnasensis BROTZEN

Recommended source for illustration:
Brotzen (1948) pl. 16, fig.4

1948 *Alabamina solnasensis* BROTZEN p.102, pl.16, fig.4

DIAGNOSIS: Test smooth almost glassy, unequally biconvex with the umbilical side more highly convex than the spiral side. Generally 5 chambers in the final whorl and a broadly rounded and lobate periphery. Sutures on spiral side depressed, straight or fairly curved. Sutures on umbilical side radial and flush, umbilicus closed. Aperture is a high, fairly narrow slit which extends into an infolded apertural face.

REMARKS: The depressed sutures and lobate periphery are diagnostic. Brotzen (1948) records this species as "...abundant in the clayish layers of Copenhagen...". However, it is only rarely recorded in this study.

RANGE: Palaeocene (Brotzen, 1948).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		rare
Pegwell Bay			**Stevns Klint**		
Reculver					

Family GLOBOROTALITIDAE Loeblich & Tappan, 1984
Genus *Globorotalites* Brotzen, 1942

Globorotalites micheliniana (D'ORBIGNY)

Recommended source for illustration:
Hart *et al.* (1989) pl. 7.14, figs 1-2

1840 *Rotalina micheliniana* D'ORBIGNY

1989 *Globorotalites micheliniana* (d'Orbigny): HART *et al.* p.342, pl.7.14, figs 1-2

DIAGNOSIS: Test free, strongly planoconvex and steeply conical on the umbilical side, normally with a narrow but deep pseudoumbilicus. Circular periphery with an acute margin with a slight keel. 6-7 chambers in the final whorl with rather indistinct sutures. Aperture a narrow, elongate, interiomarginal slit which may have a slight lip.

REMARKS: This rather distinctive species has a broad range of variation with respect to the height of the umbilical side and the width of the pseudoumbilicus. The sole occurrence of this species in the samples studied (Wormingford Mere borehole) is almost certainly due to re-working.

RANGE: Turonian - Campanian (Hart *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Family OSANGULARIIDAE Loeblich & Tappan, 1964
Genus *Osangularia* Brotzen, 1940
Osangularia navarroana **(CUSHMAN)**
Recommended source for illustration:
Hart *et al.* (1989) pl. 7.20, figs 7-8

1938 *Pulvinulinella navarroana* CUSHMAN
1989 *Osangularia navarroana* (Cushman): HART *et al.* p.354, pl.7.20, figs 7-8

DIAGNOSIS: Test free, almost equally biconvex with a moderately raised calcite boss on the umbilical side. Outline circular, periphery acute, bordered by a distinct keel. 10-12 chambers visible on the umbilical side, sutures flush though distinct. Aperture a narrow V-shaped slit.

REMARKS: *O.cordieriana* (d'Orbigny) is similar but has a less equally biconvex test and a less keeled periphery.

RANGE: Maastrichtian (Hart *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		rare
Reculver					

Family HETEROLEPIDAE Gonzales-Donoso, 1969

Genus *Anomalinoides* Brotzen, 1942

***Anomalinoides acuta* (PLUMMER)**

Recommended source for illustration:

Murray *et al.* (1989) pl.10.3, figs 1-3

1927 *Anomalina ammonoides* (Reuss) var. acuta PLUMMER p.149 pl.10 fig.2

1948 *Anomalinoides acuta* (Plummer): BROTZEN p.87 pl.15 fig.2

1951 *Anomalina acuta* Plummer: CUSHMAN p.62 pl.88 figs.3-6

1972 *Anomalinoides acuta* (Plummer): BERGGREN pl.11 fig.3

1975 *Anomalinoides acuta* (Plummer):BERGGREN & AUBERT p.149 pl.V fig.4 pl.VIII fig.3 pl.IX fig.1 pl.XII fig.5 pl.XIII fig.8 pl.XVII fig.5 pl.XVIII fig.2 pl.XIX fig.2

1976 *Anomalinoides acuta* (Plummer): AUBERT & BERGGREN p.429 pl.9 fig.1

?not 1983 *Anomalina acuta* Plummer: DOPPERT & NEELE pl.X fig.3

1989 *Anomalinoides acutus* (Plummer): MURRAY *et al.* p.512 pl.10.3 figs.1-3

DIAGNOSIS: Test a very low trochospire, almost planispiral and compressed with an acute to subacute periphery. Both sides involute with central bosses. 13-15 narrow chambers in the final whorl. Aperture a low arch at the base of the apertural face which extends onto the spiral side.

REMARKS: *C.alleni* is similar but is more lenticular in profile. *Anomalinoides nobilis* Brotzen, has a rounder periphery and fewer chambers.

A.acuta is a widely distributed species worldwide and is a common constituent of shallow water ("Midway type") Palaeocene assemblages (Berggren & Aubert, 1975). However, it is

not recorded from U.K. onshore Palaeocene sequences where it's oldest occurrence not being recorded until the London Clay (Early Eocene) of the Hampshire and London Basins (Murray *et al.*, 1989).

Doppert & Neele's record (1983) of *Anomalina acuta* from onshore Holland is rather questionable since their illustration (pl.X fig.3) shows a specimen with what appears to be a rounded periphery and approximately 10-11 chambers in the final whorl. It is also apparently distinctly trochospiral and evolute on the spiral side.

A.acuta is not recorded by Tjalsma & Lohmann (1983) from the Palaeogene of the Atlantic supporting the contention that this form is primarily a shallow water shelf dweller.

RANGE: Worldwide: Early Palaeocene - Eocene (various authors above); U.K. onshore: Early Eocene (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

<table>
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<tr><td>44/2-1</td><td></td><td>49/24-2</td><td></td><td>49/25-2</td><td></td></tr>
<tr><th colspan="6">ONSHORE</th></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td></td></tr>
<tr><td colspan="2">Pegwell Bay</td><td></td><td colspan="2">Stevns Klint</td><td></td></tr>
<tr><td colspan="2">Reculver</td><td></td><td colspan="2"></td><td></td></tr>
</table>

Anomalinoides capitatus (GUEMBEL)

Recommended source for illustration:
Van Moorkhoven *et al.* (1986) pl.92

1868 *Rosalina capitata* GUEMBEL p.653, pl.2, fig.92
1986 *Anomalinoides capitatus* (Guembel): van MORKHOVEN *et al.* p.276 pl.92
1989 *Anomalinoides grosserugosa* (Guembel): KING p.467 not illustrated

DIAGNOSIS: Test a very low trochospire, almost planispiral with a partly evolute spiral side and involute umbilical side. Umbilical side somewhat more convex though both sides flattened with a well rounded periphery. 7-8 chambers in the final whorl, the last 2-3 becoming inflated. Sutures radial, raised, developing thick ribs. Aperture a low arch at the base of the apertural face, generally nearer the periphery than the umbilicus. Wall is very coarsely perforate forming irregular raised ridges.

REMARKS: This species is very similar and closely related to *Gavelinella danica* (Brotzen) (=*Anomalinoides rubiginosus* (Cushman) of other authors) from which it appears to have evolved. It differs in the acquisition of thickened sutural ribs and larger pores however the development of large pores may be environmentally controlled (see the later discussion under *G.danica*). Transitional forms occur in the Late Palaeocene (see Tjalsma & Lohmann, 1983).

Berggren & Aubert (1975) included *A.grosserugosa* in the synonomy for *Gavelinella danica* following the studies of Hagn & Ohmart (1972) who examined Guembel's type species (*Truncatulina grosserugosa*) and concluded that it belonged to the family Victoriellidae and thus erected a new genus (*Korobkovella*) for it. They suggest that Eocene forms previously assigned to *A.grosserugosa* should be more properly assigned to *Gavelinella calymene* (Guembel) (=*Rosalina calymene* Guembel).

King (1989) however suggests that *Anomalinoides capitatus* (Guembel) would be a preferable taxonomic repository for this Eocene species. This name is also mentioned by Tjalsma & Lohmann (1983) as the end "result" of a Late Palaeocene transition from *G.danica.*

A.capitatus is also the preferred name used by van Morkhoven *et al.* (1986). They regard the species as mainly a bathyal dweller although ranging down to abyssal depths. They also describe a species *A.semicribratus* (Beckmann) which they regard as a direct descendant of *A.capitatus*. It has fewer, more rapidly increasing chambers and a less perforated wall. Forms transitional between the two exist in the early - Middle Eocene.

RANGE: U.K. offshore: Early - Middle Eocene (King, 1989). Worldwide: Late Palaeocene - earliest Oligocene (van Morkhoven *et al.*, 1986).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1	rare	**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Anomalinoides nobilis BROTZEN

Recommended source for illustration:
Murray *et al.* (1989) pl.10.3, figs 4-6

1948 *Anomalinoides nobilis* BROTZEN p.89, pl.19, fig.5
1989 *Anomalinoides nobilis* Brotzen: MURRAY *et al.*, p.512 pl.10.3, figs 4-6

DIAGNOSIS: Test a very low trochospire, almost planispiral, partly involute, umbilicus shallow, 7-9 chambers in the final whorl, sutures slightly depressed to flush, well rounded periphery, aperture a low broad arch at the base of the final chamber. Wall smooth.

REMARKS: *A.acuta* has more chambers and a subacute periphery. Other *Anomalinoides* species recorded in this study have a distinctly perforated wall. *Melonis soldanii* is similar but is completely planispiral and wholly involute.

RANGE: Late Palaeocene - Early Eocene (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		rare	**Stevns Klint**		
Reculver		rare			

Genus *Heterolepa* Franzenau, 1884

Heterolepa pegwellensis (HAYNES)

Recommended source for illustration:
Murray *et al.* (1989) pl.10.7, figs 7-9

1956 *Hollandina pegwellensis* HAYNES p.94, pl.17, fig.5
1989 *Heterolepa pegwellensis* (Haynes): MURRAY *et al.*, p.522, pl.10.7, figs 7-9

DIAGNOSIS: Test small, trochospiral, biconvex, periphery acute, "undulose" in side view, 7-9 chambers in the final whorl, 2-3 whorls visible on spiral side, sutures strongly recurved on spiral side, radial and depressed on umbilical side.

REMARKS: The small size and acute periphery are typical as is the undulating periphery in side view. Murray *et al.* (1989) state that this species is probably tolerant of poorly aerated substrates.

RANGE: Late Palaeocene (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		rare	**Stevns Klint**		
Reculver		rare			

Family GAVELINELLIDAE Hofker, 1956
Genus *Gyroidinoides* Brotzen, 1942
***Gyroidinoides angustiumbilicatus* (TEN DAM)**
Recommended source for illustration:
Murray *et al.* (1989) pl.10.6, figs 16-18

1983 *Gyroidina angustiumbilicata* Ten Dam: DOPPERT & NEELE p.60, pl.XXIII, fig.6
1989 *Gyroidinoides angustiumbilicatus* (Ten Dam): MURRAY *et al.* p.520 pl.10.6 figs.16-18

DIAGNOSIS: Test almost very unequally biconvex with the spiral side only slightly convex or flat. Umbilical side strongly convex to subconical, periphery subacute. Spiral side very evolute with 3-4 whorls visible. 8-11 chambers in the final whorl. Sutures radial on both sides, umbilicus narrow but deep. Aperture a low interiomarginal slit.

REMARKS: The illustration of *G.angustiumbilicatus* by Murray *et al.* (1989) does not appear to agree with their written description of this taxon. However, their description is close to Ten Dam's type species and the illustration of Doppert & Neele (1983) is also a good match. This species is characterised by its subconical test and radial sutures. *Gyroidinoides octacamerata* (Cushman & Hanna) is similar though is less conical and has recurved sutures on the spiral side. *Gyroidinoides soldanii girardana* (Reuss) has a very highly convex spiral side (see discussion under that species).

Murray *et al.* (1989) has recorded this species from the Solent Group of the Hampshire Basin and from the Reading Beds and London Clay of the London Basin but not from the Paris or Belgian Basins. Doppert & Neele (1983) have recorded it from the Palaeocene - Early Eocene of the Dutch onshore.

Murray *et al.* (1989) regard *G.angustiumbilicatus* as a brackish to normal marine shelf dweller that prefers muddy substrates.

RANGE: Northwest Europe: Late Palaeocene - Early Eocene (Murray *et al.*, 1989 and Doppert & Neele, 1983).

OCCURRENCE IN THIS WORK:

<table>
<tr><td colspan="6">OFFSHORE</td></tr>
<tr><td>21/26-1</td><td></td><td>49/10-1</td><td></td><td>49/24-3</td><td></td></tr>
<tr><td>29/25-1</td><td></td><td>49/20-2</td><td></td><td>49/24-4</td><td></td></tr>
<tr><td>44/2-1</td><td></td><td>49/24-2</td><td></td><td>49/25-2</td><td>rare</td></tr>
<tr><td colspan="6">ONSHORE</td></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td>rare</td></tr>
<tr><td colspan="2">Pegwell Bay</td><td></td><td colspan="2">Stevns Klint</td><td></td></tr>
<tr><td colspan="2">Reculver</td><td></td><td colspan="2"></td><td></td></tr>
</table>

Gyroidinoides danvillensis var. *gyroidinoides* (BANDY)

Recommended source for illustration:
Murray *et al.* (1989) pl.10.6, figs 19-21

1949 *Valvulineria danvillensis* var. *gyroidinoides* BANDY

1989 *Gyroidinoides danvillensis* var. *gyroidinoides* (Bandy): MURRAY *et al.* p.520 pl.10.6 figs.19-21

DIAGNOSIS: Test biconvex, almost subglobose, with umbilical side higher than spiral side and a well rounded periphery. 8-9 chambers in the final whorl, umbilicus fairly narrow. Aperture is a low broad slit at the base of a rather quadrate apertural face.

REMARKS: *G.danvillensis sensu stricto* (Howe & Wallace) has fewer chambers (6) in the final whorl. *G.danvillensis* var. *gyroidinoides* has the least convex umbilical side of any of the *Gyroidinoides* spp. described herein.

Murray *et al.* (1989) regard this species as a normal marine, inner - middle shelf dweller which is probably tolerant of poorly aerated muddy bottoms. They record it from the Thanet Beds of the London Basin but not from the Hampshire, Paris or Belgian Basins.

RANGE: U.K. onshore: Late Palaeocene (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	rare

ONSHORE			
Wormingford Mere		**Lundsgaards Cliff**	
Pegwell Bay	rare	**Stevns Klint**	
Reculver	rare		

Gyroidinoides nitidus (REUSS)

Recommended source for illustration:
Hofker (1966) pl. 3, fig. 62

1846 *Rotalia nitida* REUSS p.35, pl.8, fig.52
1966 *Gyroidinoides nitida* (Reuss): HOFKER p.27, pl.3, fig. 62
1980 *Gyroidinoides nitida* (Reuss): SWIECICKI p.318, pl.15, figs 11-13

DIAGNOSIS: Test a very low trochospire, spiral side almost flat, umbilical side distinctly convex with a distinct umbilicus. Overall test shape very well rounded. 6-7 chambers in the final whorl. Aperture a low interiomarginal slit.

REMARKS: A fairly common constituent of many Cretaceous chalk sections, though only recorded as common in some of the samples studied (i.e. 49/25-2). Somewhat unusually not recorded from the Maastrichtian chalks in Denmark although this species is thought to be rarer in the later part of the Maastrichtian in NW Europe (personal observation and also suggested by Swiecicki, 1980).

RANGE: Turonian - Maastrichtian (Hofker, 1966) but only rare in the Late Maastrichtian

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	common
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Gyroidinoides octacamerata (CUSHMAN & HANNA)

Recommended source for illustration:
Murray *et al.* (1989) pl.10.7, figs 1-3

1927 *Gyroidina soldanii* d'Orbigny var. *octocamerata* CUSHMAN & HANNA

1989 *Gyroidinoides octocamerata* (Cushman & Hanna): MURRAY *et al.* p.522 pl.10.7 figs.1-3

DIAGNOSIS: Test a rounded planoconvex trochospire with a high convex umbilical side and a well rounded periphery. Sutures oblique on spiral side, radial on umbilical side. Umbilicus open, aperture a low slit at the base of an almost flat apertural face.

REMARKS: Murray *et al.*'s (1989) description refers (presumably incorrectly) to "a high convex *spiral* side". This species in intermediate in the degree of umbilical side convexity between *Gyroidinoides soldanii girardana* (Reuss) (which is higher) and *Gyroidinoides angustiumbilicata* (Ten Dam) (which is lower). It is also distinguishable as the only *Gyroidinoides* herein with recurved spiral side sutures.

Murray *et al.* (1989) records this species from the Barton & Bracklesham Groups of the Hampshire Basin, the Cuisian - Stampian of the Paris Basin and the Ypresian - Asschian of the Belgian Basin, but not recorded from the London Basin.

RANGE: Northwest Europe onshore: Middle - Late Eocene (Murray *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Gyroidinoides soldanii girardana (REUSS)

Recommended source for illustration:
King (1989) pl.9.7, figs 15-16

1851 *Rotalina girardana* REUSS p.73 pl.5 fig.34

1975 *Gyroidinoides subangulata* (Plummer): BERGGREN & AUBERT p.148 pl.III fig.2

not 1976 *Gyroidinoides subangulata* (Plummer):AUBERT & BERGGREN p.429, pl.8 fig.6

1983 *Gyroidinoides girardanus* (Reuss): TJALSMA & LOHMANN p.14 not illustrated

1983 *Gyroidina girardana* (Reuss): DOPPERT & NEELE pl.IV fig.2

1989 *Gyroidinoides soldanii girardana* (Reuss): KING p.478 pl.9.7 figs.15-16

DIAGNOSIS: Test plano-convex with umbilical side involute, very convex and conical. Spiral side evolute and flattened with a depressed spiral suture. 8-10 broad chambers in the final whorl. Sutures radial on both sides, umbilicus narrow but deep. Aperture a relatively short, low slit at the base of a flat apertural face.

REMARKS: The highly conical and planoconvex test distinguishes this species. *Gyroidinoides cf. quadrata* (Cushman & Church) has a similar overall shape but with fewer chambers. *Gyroidinoides octocamerata* (Cushman & Hanna) is also similar but distinguishable by the recurved sutures on the spiral side and being somewhat less conical on the umbilical side.

Many different species of *Gyroidinoides* are noted in the appropriate literature: Berggren & Aubert (1975) describe one taxon, *Gyroidinoides subangulata* (Plummer), which is similar to *G.angustiumbilicata* only appears to have an even more convex umbilical side. They state that this species is a common "Midway" form and "...is one of the most widely recorded species in Palaeocene assemblages of the world". However, their illustration (particularly Pl.III fig.2) is a fairly close morphological match compared with

Gyroidinoides soldanii girardana (Reuss) of King (1989) and *Gyroidina girardana* (Reuss) of Doppert & Neele (1983). However, a subsequent illustration of *G.subangulata* by the same authors from the Palaeocene of Tunisia (Aubert & Berggren, 1976) is noticeably less conical on the umbilical side. This latter illustration appears to have more in common with *Gyroidinoides octocamerata* (Cushman & Hanna).

Both King (1989) and Doppert & Neele (1983) only record *G.soldanii girardana* from the Oligo-Miocene of northwest Europe (offshore U.K. and Dutch onshore), although Tjalsma & Lohmann (1983) record it from the Palaeocene of the North Atlantic. It is not recorded from the U.K. onshore Palaeogene succession by Murray *et al.* (1989).

Tjalsma & Lohmann (1983) describe 5 species: *G.aequilateralis, G.girardanus, G.globosus, G.*cf.*quadratus* and *Gyroidinoides* sp. from the Palaeocene of the Atlantic Ocean although illustrate only three of them. *G.girardanus* is not illustrated but these authors record it as rare to frequent in the Atlantic Palaeocene.

The taxonomy herein follows King (1989) who includes this taxon as a subspecies of *G.soldanii*. Other subspecies include *G.s.soldanii* itself (which has a more convex spiral side) and *G.s.mamillata* (Andreae) - an Oligocene form with a high conical spiral side). Intermediate forms between these three types have been recorded.

RANGE: Worldwide: Palaeocene - earliest Miocene (see above), U.K. offshore: so far only recorded from the Early Oligocene - earliest Miocene (King, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**	rare	**49/24-3**	rare
29/25-1	rare	**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**	rare	**49/25-2**	rare
ONSHORE					
Wormingford Mere		**Lundsgaards Cliff**			
Pegwell Bay		**Stevns Klint**			
Reculver					

Genus *Stensioeina* Brotzen, 1936

***Stensioeina pommerana* BROTZEN**

Recommended source for illustration:

Hart *et al.* (1989) pl. 7.24, figs 10-12

1936 *Stensioeina pommerana* BROTZEN

1989 *Stensioeina pommerana* Brotzen: HART *et al.* p.362, pl.7.24, figs 10-12

DIAGNOSIS: Test free, distinctly planoconvex, umbilical side involute and strongly domed. Outline circular, periphery acute. Umbilical region is covered by a large, irregular chamber flap. The dorsal side sutures are highly elevated, resulting in a distinct irregular reticulate network on the spiral side. Aperture a low interiomarginal arch bordered by a thick lip.

REMARKS: An easily distinguished species which can be common in Maastrichtian strata of the North Sea region.

RANGE: Campanian - Maastrichtian (Hart *et al.*, 1989) though generally rarer below the Maastrichtian in offshore sections.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		rare
Reculver					

Genus *Angulogavelinella* Hofker, 1957

***Angulogavelinella bettenstaedti* HOFKER**

Recommended source for illustration:
King *et al.* (1989) pl. 8.2, figs 7-8

1957 *Angulogavelinella bettenstaedti* HOFKER

1989 *Angulogavelinella bettenstaedti* Hofker: KING *et al.* p.412, pl.8.2, figs 7-8

DIAGNOSIS: Test free, unequally biconvex with the spiral side more convex than umbilical side. Periphery acute and keeled. 8-10 chambers in the final whorl with raised and distinctly recurved sutures.

REMARKS: The recurved sutures are distinctive.

RANGE: Late Campanian - Early Maastrichtian (King *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**	?	**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Gavelinella* Brotzen, 1942

Gavelinella baltica **BROTZEN**

Recommended source for illustration:

Hart *et al.* (1989) pl. 7.10, figs 3-5

1942 *Gavelinella baltica* BROTZEN

1989 *Gavelinella baltica* Brotzen: HART *et al.* p.334, pl.7.10. figs 3-5

DIAGNOSIS: Test free, a low biconvex trochospire with flattened sides and a rounded periphery. 8-12 slightly inflated chambers in the final whorl, increasing slowly in size except the last 3 or 4 which increase more rapidly. Sutures distinct and depressed. Aperture a low interiomarginal slit.

REMARKS: The sole occurrence of this species in the samples studied (Wormingford Mere borehole) is almost certainly due to re-working.

RANGE: Latest Albian - Late Cenomanian (Hart *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere	?		**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Gavelinella beccariiformis (WHITE)

Recommended source for illustration:
King (1989) pl.9.8, figs 18-19

1928 *Rotalia beccariiformis* WHITE p.287 pl.39 figs.2a-c
1944 *Rotalia parvula* Ten Dam: TEN DAM p.121, pl.4 fig.1
1945 *Pseudovalvulineria vombensis* Brotzen: BROTZEN p.50 pl.1 figs 12-13
1946 *Anomalina beccariiformis* (White): CUSHMAN & RENZ p.48 pl.8 figs.21-22
1962 *Gavelinella beccariiformis* (White): von HILLEBRANDT p.101 pl.8 figs.2a-c
1976 *Gavelinella beccariiformis* (White): AUBERT & BERGGREN p.433 pl.11 fig.4
1983 *Gavelinella beccariiformis* (White): KING p.33 pl.5 figs.13-15
1983 *Gavelinella beccariiformis* (White): TJALSMA & LOHMANN p.12 pl.6 figs.1-3
1986 *Stensioeina beccariiformis* (White): van MORKHOVEN *et al.* p.346 pls 113A-D
1989 *Stensioeina beccariiformis* (White): KING p.482 pl.9.8 figs.18-19

DIAGNOSIS: Test unequally biconvex and involute. A low trochospire with the spiral side slightly convex to flat and a more convex, though still somewhat flattened, umbilical side. Sutures on the umbilical side are limbate, raised and extend towards the periphery. They divide into irregular raised ridges around the umbilicus. Aperture a small low arch at the base of the apertural face, near the umbilical area. Wall coarsely perforate.

REMARKS: The umbilical suture system is a distinctive feature of this species.

The generic position of *G.beccariiformis* has been the subject of much discussion (see van Morkhoven *et al*, 1986 who includes it within *Stensioeina*). Following the classification of Loeblich & Tappan (1988), the species herein is retained within *Gavelinella* rather than *Stensioeina* due to the absence in *G.beccariiformis* of characteristic irregularly raised spiral side sutures which result in a reticulose pattern in the latter genus. Also according to Loeblich & Tappan (1988), *Stensioeina*, unlike *Gavelinella*, does not range above the Maastrichtian.

Aubert & Berggren (1976) have recorded this species in the Palaeocene of Tunisia, where they report that it is commonly found in sediments deposited under deeper water palaeoenvironments and absent in those deposited under shallower conditions.

Tjalsma & Lohman (1983) have recorded it from the Palaeocene of the Atlantic Ocean where it has a wide bathymetric distribution (800m-4000m).

King *et al.* (1989) records this species from Late Cretaceous of the U.K. Northern North Sea offshore sector (the Shetland Group) although not from the equivalent Central and

Southern North Sea lithofacies, the Chalk Group. King (1989) also records *G.beccariiformis* from the Late Palaeocene of the North Sea.

Ten Dam (1944) recorded *R.parvula* from the Late Palaeocene of Holland. This species is listed as synonymous with *G.beccariiformis* by van Morkhoven *et al.* (1986) who regard it as a shallow-water ecophenotype of their taxon. They have observed *G.beccariiformis* "proper" only from oceanic / deep-water sections and *G."parvula"* only from the Boreal province (e.g. Denmark, Belgium & Holland) of northwestern Europe. There, *G.parvula* is recorded as being "a small, densely and finely perforate form with a flat or slightly concave spiral side, a slightly open umbilicus, distinct intra-umbilical flaps extending from the chamber margins and thick umbilical sutures."

RANGE: Worldwide: Late Cretaceous - Late Palaeocene (Aubert & Berggren, 1976; Tjalsma & Lohmann, 1983). U.K. offshore: Early - intra-Late Palaeocene. This species is a useful guide fossil for the penetration of Subzone NSB1c (intra-Late Palaeocene) in the (Central and Southern) North Sea and it seldom ranges below the early Late Palaeocene, Subzone NSB1b (King, 1989). In the Northern North Sea, it is a characteristic component of Late Maastrichtian - Palaeocene microfaunas from the Shetland Group (King *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	mod. comm.	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere		rare	**Lundsgaards Cliff**		common
Pegwell Bay			**Stevns Klint**		
Reculver					

Gavelinella bembix **(MARSSON)**

Recommended source for illustration:

Hofker (1966) pl. 23, fig. 114

1878 *Discorbis bembix* MARSSON p.167, pl.5, fig.114

1966 *Gavelinopsis bembix* (Marsson): HOFKER p.148, pl.23, fig.114

1980 *Gavelinella bembix* (Marsson): SWIECICKI p.344, pl.18, figs 10-12

DIAGNOSIS: Test fairly small and planoconvex, a low trochospire with flattened spiral side with a distinct central knob. Umbilical side highly convex with a distinct umbilical plug. About 10-12 chambers in the final whorl with recurved, though somewhat indistinct sutures.

REMARKS: The two central knobs are distinctive as is the planoconvex test shape. It is differentiated from *G.voltziana* by its smaller size.

Swiecicki (1980) discusses this species (and others) as members of a plexus of gavelinellids termed the "*voltziana* plexus". Two species of that plexus are recognised here - *G.bembix* and *G.voltziana*. The two are morphologically similar though distinguishable by size although juveniles of *G.voltziana* can be very similar to *G.bembix* (Swiecicki, 1980).

This plexus can be commonly recorded in upper levels within the Chalk Group in offshore sections, where they form common constituents in Ekofisk, Tor and upper Hod Formations.

RANGE: Late Cretaceous (Maastrichtian - Swiecicki, 1980) - ?Early Danian (Hofker, 1966).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**	rare	**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Gavelinella danica **(BROTZEN)**

Recommended source for illustration:

King (1989) pl.9.4, figs 19-20

1926 *Anomalina rubiginosa* CUSHMAN p.607 pl.21 figs.6a-c
1932 *Anomalina rubiginosa* Cushman: CUSHMAN & JARVIS p.52 pl.16 figs.3-5
1940 *Cibicides danica* BROTZEN p.31 fig7.2a-c
1948 *Anomalinoides danica* (Brotzen): BROTZEN p.87 pl.14 figs.1a-c text fig.22
1955 *Gavelinella danica* (Brotzen): HOFKER p.11 pl.11 fig.1

1966 *Gavelinella danica* (Brotzen): HOFKER p.10 pl.84 fis.218,220-222

1970 *Gavelinella danica* (Brotzen): HANSEN p.108 pl.28 figs.2-4

1974 *Gavelinella danica* (Brotzen): BERGGREN pl.6 figs.1-6

1975 *Gavelinella danica* (Brotzen):BERGGREN & AUBERT p.155 pl.VI fig.3 pl.XI fig.1 pl.XIII fig.1 pl.XIV fig.4 pl.XVII fig.7 pl.XIX fig.4

1976 *Gavelinella danica* (Brotzen):AUBERT & BERGGREN p.433 pl.11 fig.5 pl.12 fig.1

1976 *Gavelinella rubiginosa* (Cushman): AUBERT & BERGGREN p.433 pl.12 fig.3

1983 *Gavelinella danica* (Brotzen): KING p.35 pl.5 figs.16-17

1983 *Gavelinella danica* (Brotzen): TJALSMA & LOHMANN p.13 pl.5 figs.7a-c

1983 *Gavelinella danica* (Brotzen): DOPPERT & NEELE pl.XXVII fig.3

1986 *Anomalinoides rubiginosus* (Cushman): van MORKHOVEN *et al.* p.366 pl.119

1989 *Anomalinoides rubiginosus* (Cushman): KING p.467 pl.9.4 figs.19-20

DIAGNOSIS: Test a very low trochospire, almost planispiral with a partly evolute spiral side and involute umbilical side. Umbilical side somewhat more convex though both sides flattened with a well rounded periphery. 7-8 chambers in the final whorl, the last 2-3 becoming inflated. Sutures radial and depressed. Aperture a low arch at the base of the apertural face, generally nearer the periphery than the umbilicus. Wall is coarsely perforate (on both sides) forming irregular raised ridges.

REMARKS: *G.danica* is a very distinctive Palaeocene species although there is a closely related and similar species in the Early - Middle Eocene referred by some authors (e.g. Franke, 1927) as *Anomalina grosserugosa* (Guembel). *A.grosserugosa* tends to develop thickened sutural ribs. Berggren & Aubert (1975) include this species within the synonomy of *G.danica*, citing the work of Hagn & Ohmart (1972) who state that Guembel's type specimen (*Truncatulina grosserugosa*) belongs to a different family. However, a discussion on the taxonomy of *A.grosserugosa* is given earlier in this study.

The form *Anomalinoides rubiginosus* (Cushman), with a smaller, more robust test and slightly larger pores, has been recorded from deep water (continental slope and abyssal plain) sediments (Cushman, 1926; Cushman & Jarvis, 1932) of the "Velasco" type. Berggren & Aubert (1975) in their study of shallower water "Midway" type facies, were not able to separate the two forms and suggest the slightly different morphologies to be depth related. Although in a slightly later publication on Tunisian material (Aubert & Berggren, 1976) they differentiated the two taxa noting that *A.rubiginosa* only occurred in the deeper deposits. Tjalsma & Lohmann (1983) agree with this hypothesis and regard *A.rubiginosus* as a phenotypic variant in which secondary calcite deposition accounts both for the larger pores and the sutural ridges.

King (1989) follows van Morkhoven *et al.* (1986) and includes *G.danica* within *Anomalinoides rubiginosus* which is the older named species (Cushman, 1926).

G.danica has a worldwide distribution (see Berggren & Aubert, 1975) and appears to prefer continental shelf rather than slope or abyssal plain habitats (where it is commonly recorded as the depth-related ecophenotype *A.rubiginosus* (Cushman) (see Tjalsma & Lohmann, 1983 and van Morkhoven *et al.*, 1986)) although it can be found in both. It is a frequent constituent of northwest European Palaeocene benthonic assemblages, both on and offshore (e.g. Brotzen, Hofker, Hansen, Doppert & Neele, King *op. cit.*). However, it has not been recorded from U.K. onshore Palaeocene localities (Murray *et al.*, 1989).

RANGE: U.K. offshore: Late Cretaceous (Campanian) - intra-Late Palaeocene (King, 1989). *G.danica* is often recovered in association with *G.beccariiformis* and appears to be a good guide fossil for the penetration of Subzone NSB1c (King, 1989). Worldwide: Late Cretaceous - Palaeocene (various authors above).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	rare
44/2-1		**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Gavelinella lorneiana (D'ORBIGNY)

Recommended source for illustration:
Hart *et al.* (1989) pl. 7.11, figs 10-12

1840 *Rosalina lorneiana* D'ORBIGNY
1980 *Gavelinella lorneiana* (d'Orbigny): SWIECICKI p.325, pl.16, figs 7-9
1989 *Gavelinella lorneiana* d'Orbigny: HART *et al.* p.336, pl.7.11, figs 10-12

DIAGNOSIS: Test free, a very low trochospiral coil of 2½-3 whorls with a rounded to subacute periphery in the early part, though becoming more well rounded later. The occasional development of an imperforate peripheral band has been noted. 8-10 chambers in the final whorl with depressed sutures. Aperture a low interiomarginal slit, bordered by

an indistinct lip, expanding into the umbilicus where it is covered by a subtriangular imperforate flap.

REMARKS: The single occurrence of this taxon in the Wormingford Mere samples is almost certainly due to reworking.

RANGE: Turonian - early Late Campanian (Hart *et al.*, 1989).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	

ONSHORE			
Wormingford Mere	rare	**Lundsgaards Cliff**	
Pegwell Bay		**Stevns Klint**	
Reculver			

Gavelinella pertusa (MARSSON)

Recommended source for illustration:
Hart *et al.* (1989) pl.7.12, figs 4-6

1878 *Discorbina pertusa* MARSSON

1980 *Gavelinella pertusa* (Marsson): SWIECICKI pp.322-323, pl.16, figs 4-6

1989 *Gavelinella pertusa* (Marsson): HART *et al.* p.338 pl.7.12 figs.4-6

DIAGNOSIS: Test a very low trochospire, partly evolute especially on the spiral side. Umbilical side involute with a wide, open and deep umbilicus. Periphery rounded. 8-9 chambers in the final whorl increasing slowly in size. Sutures indistinct, radial, flush to slightly depressed. Aperture a low interiomarginal slit. Wall coarsely perforate.

REMARKS: This is a distinctive species (characterised by the open and deep umbilicus) recorded throughout most of the Chalk Group in northwest Europe both on and offshore (see Swiecicki, 1980; Hart *et al.*, 1989 and King *et al.*, 1989). It is regarded as a reliable guide in the differentiation between the Late Cretaceous and Early Palaeocene (Danian) parts of the Chalk Group (Hod-Tor Formations and Ekofisk Formation respectively) in the North Sea Basin. However, unpublished research suggests that *G.pertusa* may range into the Early Palaeocene (Danian) of the Dutch offshore.

RANGE: U.K. on and offshore: Late Cretaceous (Coniacian) - Maastrichtian (see authors above) - ?Early Palaeocene (Danian) in some offshore areas.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		49/10-1		49/24-3	?
29/25-1		49/20-2	rare	49/24-4	
44/2-1	rare	49/24-2		49/25-2	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Gavelinella voltziana (D'ORBIGNY)

Recommended source for illustration:
Hofker (1966)

1840 *Rotalina voltziana* D'ORBIGNY p.31, pl.2, figs 32-34

1966 *Gavelinopsis voltziana* (d'Orbigny): HOFKER pp.29, 42, pl. 3, fig.63, pl.6, fig.56, pl.7, fig.124

1980 *Gavelinella voltziana* (d'Orbigny): SWIECICKI p.351, pl.19, figs 10-12

DIAGNOSIS: Test free, large, a low planoconvex trochospire with a strongly convex umbilical side with a moderate to large boss. About 9-11 chambers in the final whorl increasing gradually in size. Outline circular to weakly lobate. Sutures flush though distinct and radial to slightly curved on the umbilical side, curved on the spiral side. Surface smooth. Aperture a broad low arch, extending along the depressed spiral suture and bordered by a thick lip.

REMARKS: *G.voltziana* is similar to *G.bembix* but is generally much larger. See also "Remarks" for *G.bembix.*

RANGE: Late Campanian - Maastrichtian (Swiecicki, 1980) - ?Danian.

OCCURRENCE IN THIS WORK:

<table>
<tr><th colspan="6">OFFSHORE</th></tr>
<tr><td>21/26-1</td><td></td><td>49/10-1</td><td></td><td>49/24-3</td><td>rare</td></tr>
<tr><td>29/25-1</td><td></td><td>49/20-2</td><td>rare</td><td>49/24-4</td><td>rare</td></tr>
<tr><td>44/2-1</td><td>common</td><td>49/24-2</td><td></td><td>49/25-2</td><td>common</td></tr>
<tr><th colspan="6">ONSHORE</th></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td></td></tr>
<tr><td colspan="2">Pegwell Bay</td><td></td><td colspan="2">Stevns Klint</td><td>common</td></tr>
<tr><td colspan="2">Reculver</td><td></td><td colspan="2"></td><td></td></tr>
</table>

***Lingulogavelinella* aff. *L.gyroidinaeformis* (*sensu* MOULLADE)**

Recommended source for illustration:
King *et al.* (1989) pl. 8.2, figs 5-6

1966 *"Globigerinelloides" gyroidinaeformis* MOULLADE

1981 *"Globigerinelloides" gyroidinaeformis* Moullade: BURNHILL & RAMSAY fig.4(5)

1989 *"Globigerinelloides" gyroidinaeformis* Moullade: KING *et al.* p.412, pl.8.2, figs 5-6

DIAGNOSIS: Test almost planispiral (i.e. slightly trochospiral), about 5 globular chambers increasing fairly rapidly in size resulting in a lobate periphery. Wall smooth, calcareous and finely perforate. Aperture a low arch.

REMARKS: This species has attracted a good deal of controversy over it's taxonomic status in recent years. Originally described by Moullade (1966) from the Albian of France, it was found to be an extremely useful guide fossil for the Early - Mid Albian of offshore North Sea well sections by Burnhill & Ramsay (1981). They reported it as occurring in abundance along with abundant other planktonic taxa (*Hedbergella* spp.) and rare benthonic species. They concluded, therefore, that it was a planktonic foraminiferan but retained the *Globigerinelloides* generic assignment, even though the trochospiral mode of coiling should preclude this.

Other authors (e.g. King *et al.*, 1989) have since cast doubt on its status as a planktonic organism. King *et al.* states that it occurs abundantly but *unaccompanied* (present author's emphasis) by any other planktonic species.

Unpublished commercial research has suggested that this taxon is a benthonic organism and should be included within the genus *Lingulogavelinella.*

The specimens recorded from Lundsgaards Cliff in Denmark match well the illustrations of Burnhill & Ramsay (1981) and King *et al.* (1989). They are designated here as having "affinity" with *L.gyroidinaeformis* but are obviously not the same species in view of the significant stratigraphic difference. They are fairly well preserved and it is thought unlikely that they have been reworked.

They are similar in gross morphology to a form designated by Hofker (1966) as *Trochammina inflata* and described from Late Palaeocene clays and greensands of Denmark (herein synonymised possibly with *Trochammina volupta*). However, SEM photos of the specimens recorded from this study show that they are definitely calcareous rather than agglutinated.

RANGE: Late Palaeocene (this study).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**	rare	
Pegwell Bay			**Stevns Klint**		
Reculver					

Other taxa were recorded in the material examined, specifically where the sample analysed was comprised of ditch-cuttings, are interpreted as caved if the lower limit of their range lies in strata younger than the Late Eocene (see Chapter 4 for a description of the process of "caving"). These taxa are not described in this section although are included below in the distribution charts together with the locations at which they were recorded.

8.3.The Diatomacea

Some of the taxa recorded in this section have not been given formal names. Rather they have been assigned code numbers *sensu* unpublished research documents written by Grampian Stratigraphic Services. Diagnoses and illustrations of these taxa are, however, provided.

Genus *Coscinodiscus*

Coscinodiscus* sp.1 *sensu* BETTENSTAEDT *et al.

Recommended source for illustration:
King (1983) pl. 1, figs 1-2

1940 ?*Coscinodiscus*: STAESCHE & HILTERMANN, p. 14, pl.6
1943 *Coscinodiscus* sp. (bikonvex): WICK, pl.1, figs.47-66
1962 *Coscinodiscus* sp.1: BETTENSTAEDT *et al.* p.357, pl.52, figs 18-19
1975 *Coscinodiscus* sp.1: JACQUÉ & THOUVENIN, p.462, pl.2, figs.A-E
1983 *Coscinodiscus* sp.3: THOMAS & GRADSTEIN, p.19, pl.3.1, figs 7-12
1983 *Coscinodiscus* sp.1: KING, p.20, pl.1, figs.1-2

DIAGNOSIS: Test rather large, biconvex with a broad flat central "belt" or "girdle" which, in some specimens, exceeds the length of the circular diameter.

REMARKS: All specimens of this species recorded in this study are of pyritised internal moulds.

This taxon is well known from the Northwest European area in both on- and offshore localities. It was first described by Staesche (1938) from Eozon 1 (Early Eocene) in NW Germany. Since then it has been recorded from the lower part of the London Clay (Early Eocene) at Harwich, Bawdesy, Herne Bay and Southend (David & Elliot, 1958); the Thanet Beds (Late Palaeocene) of E.Kent (Haynes in a pers. comm. to Crittenden, 1979); the "Mo" Clay (Early Eocene) of Denmark (Bender, 1972 and Bonde, 1974); a "Mo" Clay (Early Eocene) equivalent section from the Netherlands (Berggren, 1960); and again from the Early Eocene of northern Germany (Bettenstaedt *et. al.*, 1962; Bender, 1972).

Coscinodiscus sp.*1* was also recorded from offshore European Palaeogene sediments by Knox, Morton & Harland (1981). Thomas & Gradstein (1981) also recognised it (as "species 3") in offshore Eastern Canada (Labrador Shelf and Grand Banks). Later, King (1983) recognised the stratigraphic utility of this species and used it to define Zone NSP4 which ranged from the latest Palaeocene to earliest Eocene.

Jacqué & Thouvenin (1975) linked the abundance of *Coscinodiscus* sp.*1* to the tuffaceous horizons in the North Sea Tertiary Basin. They suggest that contemporaneous volcanic activity in the area (see Chapter 2.3) may have led to silica enrichment of sea waters which in turn, encouraged diatom blooming. However, Lizitsin (1971) indicated that silica enrichment for the marine environment can be adequately provided by normal sedimentation from the erosion of silica sources onshore, rather than being directly introduced by volcanic activity itself in the form of tuffaceous deposition.

Certainly, many different species of pyritised diatom (including many taxa attributable to *Coscinodiscus*) have been recorded from throughout the Cenozoic in the offshore North Sea area not associated with tuff deposition. The occurrence of this genus, almost to the exclusion of any other microfaunal taxa in Palaeocene - Eocene tuffaceous sediments of the Balder Formation (and its equivalents offshore) may have been enhanced by other factors (see Chapter 9.1).

RANGE: Early Eocene - Late Palaeocene (see references above). The stratigraphic top of this species is used to define Bioevent M7 of Mudge & Copestake (1992). This event occurs at or near the top of the Moray Group, Balder Formation and is especially useful in distinguishing this Formation, especially in sand-rich sequences. The stratigraphic base of this species occurs near the base of the Sele Formation.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	?	**49/10-1**	mod. comm.	**49/24-3**	
29/25-1	common	**49/20-2**		**49/24-4**	
44/2-1	rare	**49/24-2**		**49/25-2**	rare
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Coscinodiscus sp.*2 sensu* BETTENSTAEDT *et al.*

Recommended source for illustration:
King (1983) pl. 1, fig. 3

1943 *Coscinodiscus* sp. (bikonkav) WICK pl.1 figs 67-89
1962 *Coscinodiscus* sp.2 BETTENSTAEDT *et al.*
1975 *Coscinodiscus* sp.2 JACQUÉ & THOUVENIN p.462, pl.2, fig.F
1981 *Coscinodiscus* sp.4 THOMAS & GRADSTEIN, p.19, pl.3.1, figs 13-16

1983 *Coscinodiscus* sp.2: KING p.20, pl.1, fig.3

DIAGNOSIS: Test rather large, circular and biconcave with the thickness about ¼ of the diameter.

REMARKS: All specimens of this species recorded in this study are of pyritised internal moulds. Similar, though smaller biconcave *Coscinodiscus* spp. occur throughout the Cenozoic of the North Sea area,

RANGE: Latest Palaeocene - Earliest Palaeocene (King, 1983). King records it as being characteristic of his NSP4 zone. The stratigraphic top of this species is used to help define Bioevent M7 of Mudge & Copestake (1992). This event occurs at or near the top of the Moray Group, Balder Formation and is especially useful in distinguishing this Formation, especially in sand-rich sequences. The stratigraphic base of this short-ranging species occurs near the base of this Formation.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	?	**49/10-1**	rare	**49/24-3**	rare
29/25-1	?	**49/20-2**		**49/24-4**	
44/2-1	mod. comm.	**49/24-2**	rare	**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Coscinodiscus sp.8 *sensu* G.S.S.

Pl.1 Fig.E

DIAGNOSIS: A small, discoidal test divided into three subrounded triangular sections giving an overall undulating appearance. The tripartite development is offset 120 degrees on the opposing sides of the test.

REMARKS: This species *may* be similar to *Actinoptychus* as figured by Brasier, 1980 (p.43 fig.7.4) and has been given the designation *A.senarius* by the Danish Geological Survey (Jutson, *pers. comm.*)

RANGE: Late Palaeocene (this study). Total range unknown.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		rare	**Stevns Klint**		
Reculver					

Coscinodiscus sp.16 *sensu* G.S.S.

Pl.1 Fig.F

DIAGNOSIS: Test small, discoidal with 5 pear-shaped, thick, radial "ribs" with "apexes" pointing in towards the centre.

REMARKS: This species has also been recorded in the Danish offshore (Jutson, *pers. comm.*).

RANGE: Late Palaeocene (this study) though also recorded from the Early - Middle Eocene in the North Sea (unpublished G.S.S. in-house research document).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		rare	**Stevns Klint**		
Reculver					

Coscinodiscus sp.20/26 sensu G.S.S.

Pl.1 Fig.G

DIAGNOSIS: Test discoidal, essentially biconcave or with a wide excavated central portion, occasionally with a rounded and raised central area.

REMARKS: This species resembles *Coscinodiscus* sp.2 *sensu* Thomas & Gradstein, 1981 (p.19, pl.3.1, figs 5-6)[7]. It is possibly referable to *Coscinodiscus morsianus moelleri* (Jutson, *pers. comm.*).

This species is normally a reliable and consistent marker whose highest occurrence often falls around 30-40 feet below that of *Coscinodiscus* sp.1 and thus provides a useful guide fossil for the lower part of the Balder Formation.

The author has observed this event in many wells drilled in the Danish offshore area and it occurs in the 29/25-1 well herein. It's apparent absence in the majority of the wells studied here may be due to the relatively high sampling interval employed (30-60 feet cf. 5-30 feet in 29/25-1) or that it's southernmost distribution limit may have been to the north of Quadrants 44 and 49.

RANGE: Late Palaeocene (this study). A useful marker species which occurs within zone NSP4.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	mod. comm.	**49/20-2**	mod.comm.	**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Triceratium*

Triceratium cf. ?abyssorum GRUNOW

Pl.1 Fig.H

1883 *Triceratium abyssorum* GRUNOW, in van Heurck pl.113 figs 1-2
1985 *Triceratium abyssorum* Grunow: FENNER in Bolli & Saunders, p.739, fig.8.31

DIAGNOSIS: Test a very small equilateral triangle with rounded apexes. The central area is slightly inflated.

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[7] Not to be confused with *Coscinodiscus* sp.2 *sensu* Bettenstaedt *et al.* 1962 herein.

<u>**REMARKS:**</u> All specimens of this taxon recorded in this study are pyritised internal moulds hence the "cf." designation of the name. Gross morphology suggests similarity with *T.abyssorum* Grunow, but it is stressed that this link is tentative.

Fenner (1985) does not include *T.abyssorum* on her range charts, though the illustration is of a specimen taken from the *O.klavsenii* Zone in the Northwest Atlantic. The *O.klavsenii* Zone is of early Late Palaeocene age and is broadly equivalent with the P3a - P3b (lower part) planktonic foraminiferal Subzones (Berggren, 1983).

<u>**RANGE:**</u> Late Palaeocene (this study). Recorded also by Fenner (1985) from the Late Palaeocene. The stratigraphic top of the *Triceratium* genus in the North Sea area is thought, by the author, to occur close to Bioevent M6 of Mudge & Copestake (1992). This event, of earliest Eocene age, occurs at or near the top of the Sele Formation.

<u>**OCCURRENCE IN THIS WORK:**</u>

<table>
<tr><td colspan="6">OFFSHORE</td></tr>
<tr><td>21/26-1</td><td></td><td>49/10-1</td><td></td><td>49/24-3</td><td></td></tr>
<tr><td>29/25-1</td><td>mod. comm.</td><td>49/20-2</td><td></td><td>49/24-4</td><td></td></tr>
<tr><td>44/2-1</td><td></td><td>49/24-2</td><td></td><td>49/25-2</td><td></td></tr>
<tr><td colspan="6">ONSHORE</td></tr>
<tr><td colspan="2">Wormingford Mere</td><td></td><td colspan="2">Lundsgaards Cliff</td><td></td></tr>
<tr><td colspan="2">Pegwell Bay</td><td></td><td colspan="2">Stevns Klint</td><td></td></tr>
<tr><td colspan="2">Reculver</td><td></td><td colspan="2"></td><td></td></tr>
</table>

Triceratium sp.*1 sensu* G.S.S.

Pl.2 Fig.A

<u>**DIAGNOSIS:**</u> Test an equilateral triangle with rather acute apexes. The central area is somewhat roundly depressed.

<u>**REMARKS:**</u> The biconcave triangular faces are distinctive. All specimens of this species recorded in this study are of pyritised internal moulds.

<u>**RANGE:**</u> Late Palaeocene (this study).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	mod. comm.	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Triceratium sp.*3 sensu* G.S.S.

Pl.2 Fig.B

DIAGNOSIS: Test an equilateral triangle with acute apexes. The central area is recessed with margins parallel to the outer triangular edges. A small circular hole is also sometimes present.

REMARKS: This taxon is distinguished by its recessed central area and circular hole although it is not certain whether or not this latter feature is of primary origin.

RANGE: Late Palaeocene (this study).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

8.4.The Radiolaria

Genus *Cenosphaera*

Cenosphaera lenticularis sensu **MUDGE & COPESTAKE**

Pl.2 Fig.C

DIAGNOSIS: A relatively large, lens-shaped radiolarian with a subacute margin and a reticulate surface.

REMARKS: Distinguished from *Cenosphaera* sp. which is essentially spherical.

RANGE: The stratigraphic top of this species is used to define Bioevent M3 of Mudge & Copestake (1992) and occurs at or near the top of the Maureen Formation. A downhole influx of the species occurs shortly below its top.

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**	?	**49/24-4**	
44/2-1		**49/24-2**	?	**49/25-2**	
ONSHORE					
Wormingford Mere		**Lundsgaards Cliff**			
Pegwell Bay		**Stevns Klint**			
Reculver					

Cenosphaera **spp.**

Recommended source for illustration:

King (1983) pl. 1, fig. 8

1983 *Cenosphaera* sp. KING p.20, pl.1, fig.8

DIAGNOSIS: A relatively large, spherical radiolarian with a reticulate surface.

REMARKS: *C.lenticularis* is lens-shaped. Spherical *Cenosphaera* spp. are recorded sporadically throughout much of the Cenozoic in the North Sea area. However, an influx of this taxon occurs within the Early - (lower) Middle Eocene interval and defines King's NSP6 zone (1983).

RANGE: Palaeocene - Pliocene

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1	rare	**49/10-1**	?	**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1	mod. comm.	**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

8.5.The Ostracoda

Genus *Cyamocytheridea*

Cyamocytheridea magna **(APOSTOLESCU)**

Recommended source for illustration:

Keen (1978) pl. 4, fig.8

1956 *Cytheridea? magna* APOSTOLESCU

1978 *Cyamocytheridea magna* (Apostoloescu): KEEN p.406, pl.4, fig.8

DIAGNOSIS: Carapace large with the highest point towards the anterior and tapered at both ends. Surface with a few ridges parallel to the anterior margin.

REMARKS: This species was recorded from the *A.morrissi* Bed from the Thanet Sands of Herne Bay by Keen (1978).

RANGE: Thanetian (Keen, 1978).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver		?			

Genus *Cytheropteron* (Sars)

Cytheropteron **spp.**

DIAGNOSIS: This genus is characterised mainly by the retrograde processes which frequently adorn the ventral parts either side of the carapace.

REMARKS: This genus is easily distinguished by the retrograde processes along the ventral lateral margins.

RANGE: Late Jurassic - Recent (Benson *et al.*, 1961).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1	rare	**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**	?	**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay			**Stevns Klint**		
Reculver					

Genus *Hazelina*

***Hazelina thanetensis* KEEN**

Recommended source for illustration:

Keen (1978) pl.11, figs 1-3

1978 *Hazelina thanetensis* sp. nov. KEEN p.420, pl.11, figs 1-3

DIAGNOSIS: Carapace with three prominent longitudinal ribs, with finely punctate surface in between then. A ridge runs parallel to the anterior margin and reticulation is present between the ridge and the anterior-ventral margin.

REMARKS: Keen (1978) distinguishes this species of *Hazelina* by the lack of reticulation over the main part of the carapace surface.

RANGE: Late Palaeocene (Thanetian) (Keen, 1978).

OCCURRENCE IN THIS WORK:

OFFSHORE					
21/26-1		**49/10-1**		**49/24-3**	
29/25-1		**49/20-2**		**49/24-4**	
44/2-1		**49/24-2**		**49/25-2**	
ONSHORE					
Wormingford Mere			**Lundsgaards Cliff**		
Pegwell Bay		rare	**Stevns Klint**		
Reculver		mod. comm.			

9.Results and Discussions

9.1.General Remarks

Considering the limitations placed on sample quality and quantity, particularly from borehole ditch-cuttings samples (see Chapter 4), microfaunal recovery from the majority of samples examined in this study was good. Most of the specimens obtained were moderately well to well preserved. In each sample, all specimens were identified to species level where possible and at least to the generic level. All species distribution data are included in the appendices (Appendix 1). Those taxa illustrated by hand-drawings are included in Appendix 2 (plates). A general description of the broad results for each major taxonomic group is given later in this chapter.

For offshore and onshore borehole data, actual counts of specimen numbers were logged into the "StrataBugs" palaeontological database system developed by StrataData Ltd. Output is in the form of a depth-scaled chart on which histograms proportional to the numbers of specimens in a sample are plotted (Appendix 1). This is particularly useful to help identification of species influxes or "floods" which may be masked by normal graphical symbols.

Samples collected from onshore outcrops which are closely spaced cannot be logged into the "StrataBugs" system. In these instances, species distribution data are shown on scaled summary logs generated in Microsoft "Excel" spreadsheets (Appendix 1).

The distribution and approximate abundance of each taxon in one of six fossil groups (planktonic, calcareous benthonic and agglutinated foraminifera, siliceous microfossils, ostracods and "other" types) recorded in this study are also displayed in the appendices Appendix 1). These provide an approximate guide to each taxon's geographical range within the study area.

In the discussion of the interpreted biostratigraphy for each North Sea well section analysed, the biostratigraphic zonation scheme used throughout (as described in Chapter 7) is that of King (1989); i.e. "NSP", "NSB" & "NSA" zones. Where departure from this scheme occurs (e.g. reference to the "M" bioevents of Mudge & Copestake, 1992) this will be indicated in the relevant place. Where analyses of samples extends down into the Upper Cretaceous, the published "FCS" zonation scheme of King *et al.* (1989) is used.

9.2. Planktonic Foraminifera

Planktonic foraminiferal recovery in the samples studied is very variable with high abundances yielded by samples of Late Cretaceous, Early Palaeocene (Danian) and Early Eocene age. They are noticeably rarer or absent in samples of Late Palaeocene (Thanetian) age, particularly where agglutinated faunas of the "*Rhabdammina* biofacies" are relatively well developed (see below).

In the Late Cretaceous (essentially the Maastrichtian), simple "globigerine" types (mainly *Globigerina* spp. *sensu lato* & *Archaeoglobigerina* spp.), planispiral (e.g. *Globigerinelloides* spp.), bi- or multi-serial types (*Heterohelix* spp., *Pseudotextularia* spp. and *Racemiguembelina* spp.) and non-keeled "hedbergellids/globotruncanids" (*Hedbergella* spp. and *Globotruncanella* spp.) dominate. Keeled "globotruncanids" (*Globotruncana* spp.) and thicker-walled "globigerine" types (*Rugoglobigerina* spp.) are very rare, or at best only moderately common in a few isolated samples. This would seem to suggest that Maastrichtian palaeodepths over the study area (i.e. the North Sea south of Latitude 56°N) were comparatively shallow, though open marine circulation was good. The lack of suitably deep waters would have inhibited the ability of keeled species to survive and/or reproduce (see Chapter 2).

The scarcity of keeled taxa in the Maastrichtian sequences encountered in the study area prevents the use of a detailed biostratigraphic subdivision of this interval. King *et al.* (1989) has a three-fold subzonal subdivision of the Maastrichtian of the Chalk Group (i.e. Central and Southern North Sea) with Zones FCS 23 and 22 (including Subzones a and b). However, in the Shetland Group facies (Northern North Sea), a six-fold subdivision is possible (Subzones FCN 21a-b and FCN 20a-d) with some subzonal boundaries based on highest or lowest occurrences of keeled taxa. This notwithstanding, Maastrichtian planktonic foraminifera form distinctive assemblages and are crucial in the ability to differentiate between the lithologically similar Ekofisk and Tor Formations of Early Palaeocene and Latest Campanian to Maastrichtian ages respectively, the uppermost two Formations of the Chalk Group.

A major turnover in the planktonic microfauna occurs over the Cretaceous - Tertiary boundary (equivalent to the Tor - Ekofisk Formation boundary within the Chalk Group). All Maastrichtian taxa disappear (or at least change their taxonomic status) to be replaced in the Early Palaeocene (Danian) taxa of predominantly simple morphologies dominated by "globigerine" types (*Globigerina* spp. (*sensu lato* i.e. includes *Subbotina* spp.), *Eoglobigerina* spp. and *Globoconusa* spp.), bi- and tri-serial types (*Chiloguembelina* spp. and *Guembelitria* spp.) ana non-keeled *Globorotalia* spp. and *Morozovella* spp.

Here, palaeoenvironmental (specifically water depth) interpretation is less certain. The apparent absence of keeled or thick walled taxa (the presence of which may be used as indicators of relatively increased water depth) can be explained by evolutionary effects (see Chapter 2). However, certain other evidence (benthonic macrofaunal evidence recorded, and sedimentary structures shown in onshore localities - see Chapter 3) suggests that Danian water depths around the study area were relatively shallow, with the sea floor possibly within wave-base influence.

After the end of limestone (i.e. Ekofisk formation) deposition, sometime in the Early Palaeocene, planktonic foraminifera persisted for a short time as evidenced by their occurrence (albeit in relatively low numbers) throughout much of the lower part of the Maureen Formation. These forms continue to be of relatively simple morphological types (e.g. *P.compressa* and *M.pseudobulloides*) although they are more advanced in evolutionary terms than those recorded previously.

Planktonic foraminifera are apparently absent from the overlying clastic units of the Lista and Sele Formations. This can largely be explained by the adverse environmental conditions prevailing at that time. In the south of the study area, the majority of microfaunal assemblages from this interval are dominated by calcareous benthonic taxa (see below) which suggest sediments were laid down under marine shelf conditions, though palaeodepths were comparatively shallow. This, together with the premise that this part of the North Sea area was, effectively, closed during the Late Palaeocene with open-marine communication only towards the north (see Chapter 2), would indicate difficulties for true oceanic planktonic taxa to invade and colonise this area.

In addition to this, data from wells further to the north of the study area (and the vast majority of wells further northwards again) show microfaunas from these units dominated by agglutinated taxa of the "*Rhabdammina* biofacies". The palaeoenvironmental significance of this biofacies has been discussed in Chapter 2, concluding that while the existence of a thriving planktonic biomass would be possible in the surface waters, the chances of preservation of fossil representatives of this biomass would be extremely unlikely due to adverse post-mortem burial effects.

Unfortunately, these adverse conditions effectively prevent the occurrence of more complex and stratigraphically useful taxa in the North Sea Basin. These taxa, particularly the so-called angulo-conical morozovelliids (see Chapter 7) would have been extremely useful in inter-regional correlation of the Late Palaeocene North Sea interval.

However, a point worthy of note is the abundant occurrence of two (?new) planktonic taxa (*Globorotalia* sp.A and *Globorotalia* sp.B) from the 29/25-1 well. These 2 forms

(described in Chapter 8) were recorded from sidewall core samples located mainly within the Earliest Eocene - Latest Palaeocene and uppermost Late Palaeocene intervals. As previously noted, these two forms morphologically resemble two Cretaceous species, respectively; *Hedbergella planispira* and *Hedbergella delrioensis*. Their occurrence from this specific interval from the 29/25-1 well alone is anomalous in the context of the microfaunas recorded from elsewhere in this study (?reworked) and certainly a subject for further investigation.

For possibly similar reasons to those described above, planktonic foraminifera are also generally absent from the tuffaceous units of the overlying Balder Formation, although evidence for a thriving biomass of some description can be seen from the abundant diatomaceous flora preserved in those sediments.

Planktonic foraminifera do not (significantly) re-appear in the stratigraphic section until into the Early Eocene when they are recorded in significant numbers (mainly as relatively simple types i.e. *Subbotina* spp.) from the sediments immediately overlying the Balder Formation. These sediments (which may equate at least in part to the Danish Rosnæs Clay unit of similar age) probably represent the initial transgressive phase of the subsequent major "Stamp-type" sedimentary cycle.

Planktonic foraminifera from younger Eocene intervals are recorded in abundance from most of the well sections studied. These are dominated by planispiral forms (*Globanomalina* spp.) and less common "hispid" taxa (*Acarinina* spp.) although their status as *in situ* or caved in the sample material cannot be determined with certainty. Their abundances indicate that open oceanic conditions in the surface waters throughout the remainder of the Eocene (at least) were probably good. However, the relatively simple morphologies of these taxa (compared to other contemporaneous Eocene species) suggests that palaeodepths may not have been high (i.e. c.50m-200m cf. 200m+). As before, the author has noted from the study area and other North Sea wells that planktonic taxa are generally subordinate where the "*Rhabdammina* biofacies" is well represented.

9.3. Calcareous Benthonic Foraminifera

Calcareous benthonic foraminifera are the most abundant group of microfossils recorded in this study and dominate microfaunal assemblages at all localities except where Palaeocene and Lower Eocene strata are developed in the "*Rhabdammina* biofacies" (see below).

In the chalk facies (inclusive of Maastrichtian - Early Palaeocene where present), *Gavelinella* spp., *Gyroidinoides* spp. and *Praebulimina* spp. are particularly common and

are the dominant genera, with *Angulogavelinella* spp., *Bolivinoides* spp., *Bolivina* spp., *Cibicides* spp., *Eouvigerina* spp., *Globorotalites* spp., *Loxostomum* spp., *Osangularia* spp., *Quadrimorphina* spp., *Reussella* spp., *Rosalina* spp., *Stensioeina* spp., *Stilostomella* spp. and *Tappanina* spp. less common. The overall assemblages are indicative of normal marine, general carbonate shelf conditions with well oxygenated bottom waters. However, this is not to say that the deposition of (particularly) the Tor Formation was straight forward and continuous. Phases of intense reworking of Maastrichtian taxa due to slumping of material from the graben margins have been recorded, mainly within the middle part of the Maastrichtian, from other areas of the Central Graben (Bailey *pers. comm.*, Kennedy, 1987). This is often manifested by horizons (observed by the author) of abundant representatives of generally monospecific calcareous benthonic taxa (e.g. *Reussella szajnochae szajnochae*) or bivalve debris (*Inoceramus* fragments). Unfortunately, sample coverage in this study is insufficient to adequately demonstrate these features in the wells examined.

Calcareous benthonic foraminiferal turnover at the Cretaceous - Tertiary boundary (Tor - Ekofisk Formation junction) is almost as striking as that displayed by the planktonic foraminifera. Most, though not all, of the genera listed above either disappear entirely (e.g. *Angulogavelinella* spp., *Bolivina* spp., *Bolivinoides* spp., *Globorotalites* spp., *Osangularia* spp., *Reussella* spp. and *Praebulimina* spp.), or undergo a major turnover at the specific level.

Post-chalk Palaeocene facies assemblages again are markedly different from their predecessors. Cibicidiid taxa (e.g. *Cibicides & Cibicidoides* spp.) are by far the most dominant component of the calcareous benthos, especially from some levels of the onshore U.K. sections studied although, locally, *Bulimina* spp. can also be abundant. Taxa which can be locally common include *Astacolus* spp., *Dentalina* spp., *Epistominella* spp., *Glandulina* spp., *Globulina* spp., *Guttulina* spp., *Gyroidinoides* spp., *Lenticulina* spp., *Nodosaria* spp and *Uvigerina* spp.. Other taxa which are less common include *Alabamina* spp., *Angulogerina* spp., *Anomalina/Anomalinoides* spp., *Asterigerina* spp., *Brizalina* spp., *Cancris* spp., *Eouvigerina* spp., *Eponides* spp., *Frondicularia* spp., *Heterolepa* spp., *Lagena* spp., *Lamarkina* spp., *Marginulina/Marginulinopsis* spp., *Melonis* spp., *Nonion/Nonionella* spp., *Planulina* spp., *Pseudonodosaria* spp., *Pullenia* spp., *Quadrimorphina* spp., *Trifarina* spp., *Turrilina* spp. and *Vaginulinopsis* spp.

Again, this appears to be at variance with the assemblages more widely reported from the majority of North Sea wells published, which lie mainly to the north of the study area, where agglutinated taxa of the "*Rhabdammina* biofacies" have been recorded.

The majority of wells studied herein are from the basin margins of the North Sea area rather than from the structurally deeper centres of deposition in, and close by, the South Central, Central and Viking Grabens. It is probable that the physical and chemical conditions necessary for the development of the "*Rhabdammina* biofacies" (see below and Chapter 2 for a review of these) were not able to develop in these relatively shallower waters. Thus, microfaunas from these wells (and the onshore UK and Danish sections) are represented by more "normal" (though shallow) marine shelf assemblages dominated by calcareous benthonic taxa.

The taxa listed above seem, on the whole, to be best related to the so-called Inner Sublittoral (mainly the onshore UK sections) and Outer Sublittoral - Epibathyal (mainly the offshore and Danish sections) biofacies of King, 1983, (see Chapter 7). For the offshore and Danish material, the shallower of the two depth-related subfacies which comprise the Outer Subittoral - Epibathyal biofacies would appear to be more likely. These are comparable to the "Midway type" assemblages of Berggren & Aubert (1975) and suggest water depths of between 50m-200m.

Given the proposed palaeogeographical setting for much of the southern part of the study area during the Late Palaeocene, together with the proposition that the primary control on Early Palaeogene sedimentation in the southern North Sea area is fluctuating sea levels governing shoreline position (see Chapter 6.5), it would seem that the lateral and vertical distribution of the benthonic assemblages would be more markedly affected by this than those assemblages from deeper areas (i.e. over the main North Sea grabens) where sea-level fluctuations would have less effects on the deeper habitats.

The presence of a relatively diverse and abundant calcareous foraminiferal benthos indicates that bottom waters where they are recorded were probably well oxygenated. However, some cibicidiids, particularly those species recorded in abundance from onshore UK samples, are known to tolerate brackish conditions (Murray *et al.*, 1989) and seldom occur deeper than middle shelf palaeodepths (c.50m-100m). *Bulimina trigonalis*, also recorded in abundance from onshore UK samples, is also thought to be tolerant of bottom waters with reduced oxygen levels (Murray *et al.*, 1989).

9.4. Agglutinated Foraminifera

Agglutinated foraminifera are present in most of the localities studied. They are particularly abundant in North Sea wells 29/25-1, 44/2-1 and 49/10-1 where, in some samples, they dominate the foraminiferal populations.

Ammodiscus spp., *Glomospira* spp. and *Haplophragmoides/Recurvoides/Cyclammina* types are the dominant components with *Reticulophragmium* spp., *Spiroplectammina* spp., *Rhizammina* spp., *Praecystammina* spp., *Trochammina* spp. and *Karreriella* spp. also common. Other taxa recorded include *Ammobaculites* spp., *Clavulina* spp., *Cribrostomoides* spp., *Gaudryina* spp., *Marssonella* spp., *Matanzia* spp., *Reophax* spp., *Rzehakina* spp. and *Thurammina* spp.

The agglutinants are typical of the "*Rhabdammina* biofacies" of King, 1983, which can be indicative of certain palaeoecological conditions characteristic of a particular physico-chemical environment (see Chapter 2 for a more extensive discussion). It has been shown previously that these characteristics are suggestive of, though not restricted to, palaeoenvironments of relatively large water depths with restricted water circulation which promotes dysaerobic / reducing conditions in the bottom waters or at or below the sediment/water interface. Such conditions, if severe, may completely inhibit the existence or preservation of calcareous organisms, resulting in assemblages composed exclusively of agglutinated foraminifera and, possibly, non-calcareous microfossils (e.g. diatoms and radiolaria).

As shown in Chapter 2, maximum palaeodepths during the Palaeocene occurred in the central parts of the North Sea area, particularly above pre-Jurassic structural grabens and half-grabens in and around the junction between the Witch-Ground, Central and Viking Grabens. Wells drilled in these areas often yield Palaeogene microfaunas typical of the "*Rhabdammina* biofacies" composed exclusively of agglutinated foraminifera. The three wells in this study that are dominated (though not exclusively) by abundant agglutinated foraminifera (29/25-2, 44/2-1 & 49/10-1) were all drilled just westwards and outside the limits of the Central Graben, specifically on the Western Platform and Mid North Sea High (see Text Figure 1). Possibly due to the location of these wells on relative depositional "highs", palaeodepths during the Late Palaeocene (and afterwards) may not have been sufficiently great to allow the formation of the required conditions necessary to promote development of full "*Rhabdammina* biofacies" assemblages. Also, the relatively shallower conditions along the graben margins may have been occasionally influenced by surface-generated currents that would have sufficiently mixed the water column, introducing aerobic waters near or at the sea floor.

9.5.Siliceous Microfossils

Siliceous microfossils recorded in this study are predominantly planktonic diatoms of the genera *Coscinodiscus* and *Triceratium*, plus radiolaria of the genus *Cenosphaera*, together with (caved) "*Bolboforma*", an organism of uncertain affinity (first described from the

Oligo-Miocene of Germany by Daniels & Spiegler, 1974) but thought to be possibly associated with planktonic algal cysts (Murray, 1979).

The diatoms are confined to offshore borehole material only and are most common and diverse only around the wells of the Central North Sea, particularly well 29/25-1. Their apparent decline in numbers in wells from south of the study area and absence from onshore sections examined is probably related to the southernmost limit of deposition ashes and tuffs of the Balder Formation (and equivalent onshore units), with which they are closely associated (see Chapter 2). Another possibility is the insufficiently close sampling intervals employed in most of the wells sections studied, which is due to incidental and unrelated engineering factors rather than any particular geoscientific significance.

Somewhat anomalous then, is their apparent scarcity in samples examined from the most northerly well of the study, well 21/26-1D, situated near the northeastern margin of the Western Platform. Boreholes drilled from the nearby Central Graben often yield abundant diatom assemblages which are a useful aid to correlation. Approximately 300 feet of Palaeocene sediments of suitable age were recorded from this well although it should also be noted that the recovery of other fossil groups, particularly agglutinated foraminifera, is also sporadic. One possible explanation is that palaeodepths over this locality during this time were insufficiently great to allow the establishment of a viable plankton. The palaeogeographic maps of Rochow (1981) show this part of the North Sea area to be a region of non-deposition in Palaeocene times, whilst Knox *et al.* (1981) show Upper Palaeocene isopachytes of less than 100m in the same area (cf. c.1100m for equivalent sediments in the Outer Moray Firth area).

Several authors have proposed hypotheses to account for the presence of diatoms in certain levels of the North Sea Tertiary Basin. Bonde (1974) envisaged the North Sea Basin during Palaeocene - Eocene times as being almost fully enclosed with an opening only to the north via the Norwegian Sea. Prevailing winds blowing from the north west created surface currents causing an offshore divergence to form. The resulting upwelling brought nutrients to the surface which encouraged and nourished a rich plankton throughout the area. The upwelling system would, in turn, cause a subsurface counter current which would remove subsurface nutrients leading to reduced oxygen levels at the sea floor. The activities of the rich surface flora and fauna would also consume much oxygen thus adding to the oxygen deficiency at the sea floor. This has important implications for the benthonic communities at this time (see above).

Later, Jacqué & Thouvenin (1975) linked the abundance of *Coscinodiscus* spp. in the tuffaceous Balder Formation to silica and/or CaO enrichment of sea waters by volcanic activity which is conducive to diatom blooming. Previously, however, Lizitin (1971) had

demonstrated that silica enrichment of sea waters by normal erosion of silica rich sources and normal sedimentation was adequate to sustain planktonic life with siliceous affinity. This is supported by the presence of high diatom levels in the surface waters of the present-day Antarctic Ocean which has no direct volcanic source of silica.

Of further significance is the fact that all the diatoms recorded in this study have been specimens of pyritised internal moulds. Pyrite can be produced by the slow biological decomposition at the sediment/water interface under anoxic conditions. Anaerobic bacteria thrive under these conditions and produce H_2S which, in turn, can react to produce pyrite, frequently replacing the siliceous tests of certain microfossils. Berggren (1960) states that pyrite can be indicative of a reducing environment (see also above). Reducing conditions at the sediment/water interface can have a marked effect on the preservational characteristics of other microfaunal groups, i.e. calcareous tests (benthonic and planktonic foraminifera, nannofossils etc.) can readily dissolve and thus, upon burial, remove evidence of a thriving plankton.

Thomas & Gradstein (1981) discuss the presence of *Coscinodiscus* spp. in borehole material from offshore Canada. The vast majority of these specimens are also of pyritised internal moulds. The Canadian diatom peaks are recorded at two stratigraphic levels - the Early Eocene and Miocene, which are broadly correlatable with those recorded from NW Europe with the main abundance peak being recorded in the Early Eocene (abundances in the Miocene of NW Europe are not high but there appears to be an increase in species diversity around this time). Unlike NW Europe however, they are not associated with any contemporaneous volcanic activity on the Canadian Shelf. This casts some doubt therefore on Jacqué & Thouvenin's 1975 hypothesis.

Thomas & Gradstein show that the Canadian Shelf diatom-rich sediments were deposited under neritic and bathyal conditions and possibly reflect higher nutrient levels in the upper water mass. They also show that the Miocene and Early Eocene abundance peaks correlate broadly with the periods of maximum northward excursion of lower latitude surface waters which may have led to improved surface water mixing and slope upwelling due to convergence. They concur with Berggren's 1960 view that the pyritised nature of the moulds indicates a weakly reducing or reducing diagenetic regime.

The radiolaria (*Cenosphaera* spp. and *?Cenodiscus* spp.) belong to typical open marine genera whose palaeoenvironmental significance is limited. However, as discussed above, some may remain as fossil in sediments otherwise devoid of calcareous representatives due to secondary dissolution.

9.6.Other Groups

Other microfaunal components recovered from samples analysed in this work contain rare and sporadic examples of ostracods (including *Bairdia* spp. and *Cytheropteron* spp.), fish-teeth and brachiopod fragments. Other components (recorded as "indeterminate spheres / discs") are of uncertain affinity and may or may not be of organic origin (?calcispheres). Certain types of greenish glassy spherules recovered from some of the North Sea boreholes were at first thought to possibly be examples of microtectites, related to volcanic discharge or a hypothetical impact event at the Cretaceous - Tertiary boundary. Several specimens were sent to Dr. Bill Glass of Colorado University for confirmation but spectral analysis revealed their composition to be mainly of compounds of the element Boron and are, therefore, probably some sort of drilling-mud additive contaminating the ditch-cuttings samples.

9.7.Well 21/26-1D

Microfaunal recovery from this well was relatively poor in the clastic interval above the limestones of the Chalk Group (c.3495' as picked on the log trace). Abundant planktonic foraminifera were recovered from the limestones. Intervals were delineated as follows:

2860' - 3270': EARLY EOCENE, YPRESIAN, NSB3 ZONE (top not seen)

The presence of *Turillina brevispira* at 2950' is indicative of an Early Eocene age. This species is restricted to Zone NSB3 (King, 1989). The single occurrence of *Planorotalites chapmani* at 3100' provides supporting evidence for this age assignment. This species ranges from the "Middle" Palaeocene - Early Eocene (Stainforth *et al.*, 1975). The occurrence at 3050' of a specimen questionably assigned to *Coscinodiscus* sp.*1* is considered reworked in the light of further evidence below.

3270' - 3300': LATEST PALAEOCENE - EARLIEST EOCENE, THANETIAN - YPRESIAN, NSP4 ZONE.

The highest occurrence of consistent *Coscinodiscus* sp.*1* at 3270', together with assemblages in this interval containing common pyritised diatoms, is indicative of an earliest Eocene - latest Palaeocene age. Rarer planktonic foraminifera recovered from this interval are considered caved. The highest occurrence of this taxon defines Bioevent M7 of Mudge & Copestake, 1992, an event which aids identification of the Balder Formation.

3300' - 3495' (log): LATE PALAEOCENE, THANETIAN, NO ZONES ASSIGNED

The highest occurrence at 3300' of specimens questionably assigned to *Bulimina trigonalis* suggests a Late Palaeocene, Thanetian age for this interval. Assemblages from this interval are of low abundance and diversity and no further zonal differentiation is possible. However, the absence of characteristic short-range markers, i.e. *Cenodiscus* influx (Zone NSP2 (King, 1989); Bioevent M3 (Mudge & Copestake, 1992)) tentatively suggests the presence of a hiatus within this interval. Zones NSP2 and parts of NSP3/NSB1c are inferred to be missing.

3495' (log) - 3610': EARLY PALAEOCENE, DANIAN, NSP1c-a SUBZONES.

The highest occurrences at 3520' of both *Morozovella pseudobulloides* and *Planorotalites compressa* indicate an age no younger than Subzone NSP1c at that depth. These species are largely confined to the Danian although their youngest recorded occurrences can be higher and occur near the top of the Maureen Formation. However, the wireline log trace clearly shows a typical Chalk Group response (below 3495') which indicates penetration of the Danian Ekofisk Formation.

The highest occurrence at 3540' of assemblages comprised almost exclusively of planktonic foraminifera dominated by *Subbotina* and *Eoglobigerina* (specifically *S.triloculinoides,* and *E.eobulloides s.l.*) together with common *P.compressa* and *Globorotalia archaeocompressa*, confirm an Early Palaeocene, Danian age for this interval.

3610' - 3650': ?LATE CRETACEOUS, ?LATE MAASTRICHTIAN, FCS 23 ZONE (base not seen)

The occurrence at 3610' of a single specimen questionably assigned to *Pseudotextularia elegans* provides evidence for the possible penetration of the Late Cretaceous at that depth. *P.elegans* is restricted to the latest Maastrichtian of the North Sea area. However, it should be stressed that this single specimen occurs within an assemblage dominated by Danian taxa as described above and its presence may be a result of reworking.

ADDITIONAL COMMENTS:

This well, being the most northerly well examined in this study and relatively close to the "classic" areas of Palaeocene development in the Central / Viking Graben and Outer Moray Firth areas, yielded disappointing microfaunal assemblages. This is probably due to its position situated on the Western Platform, some 30 km west of the West Central Graben and about 60 km south of the South Halibut Basin. Palaeodepths in this area during the

post-Danian Palaeogene were probably very shallow (as indicated on palaeogeographic maps of the area - see Chapter 2) and subaerial exposure may even have occurred occasionally. Palaeodepths were certainly far too shallow to allow the development of a "*Rhabdammina* biofacies" although the presence of (albeit rare) Palaeogene planktonic foraminifera throughout most of the post-Danian (when *in situ*) does suggest at least moderately normal marine conditions. The general paucity of calcareous benthonic foraminifera recorded from this well could therefore be considered unusual.

9.8.Well 29/25-1

Microfaunal recovery from this well was variable. Data from several of the sidewall cores supplied are difficult to evaluate given a typical North Sea Palaeocene succession from this area (see below). Leaving data from the "anomalous" sidewall core samples aside, the following intervals were delineated:

5800' - 5856' (log): EARLY EOCENE, YPRESIAN, NSB4-3 ZONES (top not seen)

The highest occurrence of *Spiroplectammina navarroana* is indicative of an Early Eocene age and ranges throughout Zones NSB4 and most of NSB3 (King, 1989). This interval is comprised almost exclusively of agglutinated foraminifera including *Reticulophragmium* spp. (including *R.amplectens*), *Haplophragmoides* spp., *Trochammina globigeriniformis, Rhizammina indivisa, Karreriella conversa, Ammodiscus cretaceus* and *Bathysiphon discreta*, together with other rarer taxa. The occurrence of a specimen of *Spiroplectammina spectabilis* (no younger than intra-Late Palaeocene) at 5840' is considered reworked in the light of further evidence below.

5856' (log) - 5944' (swc): LATEST PALAEOCENE - EARLIEST EOCENE, THANETIAN - YPRESIAN, NSP4 ZONE (?part).

The wireline log break (high gamma peak) at 5856' is a characteristic feature of the top of the Balder Formation. Biostratigraphic confirmation is provided by the highest occurrence of abundant pyritised diatoms including *Coscinodiscus* spp. 1 & 2 and *Triceratium* spp. (*Triceratium* cf. *abyssorum*, plus *Triceratium* sp.1 & 3 at 5872' (swc). Assemblages from this interval also include subordinate agglutinated foraminifera dominated by undifferentiated *Haplophragmoides / Reticulophragmium* spp.

This distinctive diatom assemblage is characteristic of Bioevents M7 and M6 of Mudge & Copestake (1992) and provides a reliable guide to the presence of the Moray Group, Balder and Sele Formations. However, *Coscinodiscus* sp.2 is only recorded from 5872'

(swc) above the downhole incoming of *Triceratium* spp.. This taxon is restricted to the Balder Formation, whereas all other *Coscinodiscus* species recorded from the Balder also range down to the base of the underlying Sele Formation (Mudge & Copestake, 1992). This suggests that only the upper part of this interval should be assigned to the Balder Formation

5944' (swc) - 6132' (log):LATE PALAEOCENE, THANETIAN, NSP4 ZONE (?part) / NSA1 ZONE.

The highest occurrence of presumed in-situ *Spiroplectammina spectabilis* occurs at 5944' (swc). This indicates an age no younger than the intra-Late Palaeocene NSA1 Zone at this depth. The highest occurrence of this taxon is a useful guide to the top of the Montrose Group, Lista Formation, in the Central North Sea (Bioevent M5 of Mudge & Copestake, 1992).

However, the pyritised diatom *Coscinodiscus* sp.*1* is recorded consistently in both cuttings and sidewall core samples down to 6037' (swc) and the additional index species *Coscinodiscus* sp.20/26 also occurs between 5944' (swc) - 6000'. According to King (1989) the lowest occurrence of common *Coscinodiscus* spp. marks the base of Zone NSP4 which is coincident with the top of Zone NSA1 i.e. the ranges of *S.spectabilis* and common *Coscinodiscus* spp. should not therefore overlap. Likewise Mudge & Copestake (1992) state that *Coscinodiscus* sp.*1* does not range below the Sele Formation.

Occasional records of reworking of the "impoverished agglutinants" from the top Lista Formation, (Bioevent M5 of Mudge & Copestake, 1992) into the Sele Formation has been recorded in the nearby Nelson Field area (Bailey, *pers. comm.*). This could explain the apparent overlap in ranges of *Coscinodiscus* sp.*1* and *S.spectabilis* observed herein.

Assemblages throughout this interval are comprised almost exclusively of agglutinated taxa and pyritised diatoms, although very rare undifferentiated planktonic and calcareous benthonic foraminifera are also recorded. Assemblages are similar in composition to those of the overlying interval although abundances are higher.,

Taxa providing evidence for the presence of either the early part of the Late Palaeocene (Zones NSB1c-b and Zones NSP2-1c) or the Early Palaeocene - Danian (Zones NSB1a and NSP1b-a) were not forthcoming from this well. Consequently the presence of a hiatus is indicated between this and the underlying interval. However, it should be noted that sample spacing is relatively large over this part of the section examined (c.30' - 50') which may account for the apparent absence.

6132' (log) - 6156' (swc): LATE CRETACEOUS, LATE MAASTRICHTIAN, ZONE FCS23 (base not seen)

The wireline log break (sharp reduction in gamma ray and increase in sonic velocities) at 6132' indicates penetration of the Chalk Group. Biostratigraphic evidence (the presence of *Pseudotextularia elegans* and *Racemiguembelina fructicosa*) in the sample at 6140' (swc) indicates a Late Cretaceous, late Maastrichtian age (Zone FCS23 of King *et al.*, 1989) which in turn indicates the penetration of the Tor Formation. This would appear to suggest that the uppermost Chalk Group formation, the Ekofisk Formation of Early Palaeocene (Danian) age is absent in this well. Other taxa present in this interval which are consistent with this age assignment include *Heterohelix* spp., *Hedbergella* spp., *Globigerinelloides praerihillensis, ?Rugoglobigerina* spp., *Gyroidinoides nitidus, Bolivinoides draco, Praebulimina laevis* and *Osangularia navarroana.*

ADDITIONAL COMMENTS:

The sidewall cores at 5902', 5905', 5925', 5929' 5976', and 6014' all contain high numbers of orange-stained planktonic foraminifera which were logged as *Globorotalia* sp.A ?sp.nov. and *Globorotalia* sp.B ?sp.nov. Upon further investigation, these specimens were found to be very similar to the Cretaceous species *Hedbergella planispira* (Tappan) and *Hedbergella infracretacea* (Glaessner) / *H.delrioensis* (Carsey) respectively. No records of any Palaeocene or Early Eocene planktonic taxa resembling these two forms have previously been described formally.

H.planispira is commonly recorded, in abundance, from late Albian intervals in the North Sea Basin, although the particular colouration is not characteristic. *H.infracretacea* is commonly recorded, in abundance, from early Aptian and early Barremian strata in the same area and does display a distinctive orange/red staining in the Aptian occurrences. Both taxa, however, have a range encompassing the Barremian - Cenomanian interval in the North Sea area.

Various workers (Mears *pers. comm.*, Jutson *pers. comm.* and Holmes *pers. comm.*) have noticed similar "anomalous" occurrences of these taxa from elsewhere in the Palaeogene of the North Sea Basin. There appears to be a reworking "event" of Early Cretaceous taxa into Upper Palaeocene sediments which is sporadically recorded in the North Sea area, possibly from exposed rotated fault blocks with Lower Cretaceous (probably Aptian-Albian) crests.

These taxa, though very abundant, were only recovered from sidewall core samples and did not appear in ditch cutting material, even when in close proximity.

Other sidewall cores studied from this well (5872', 5875', 5944', 6005', 6037', 6040', 6052', 6107', 6140' and 6156' all contained a "normal" microfauna for the ages assigned to them. The sidewall core at 5890', however, contains a typical Late Palaeocene microfauna with rare specimens of *Globorotalia* sp.*A* and *Globorotalia* sp.*B*.

This well lies, like 21/26-1D, on the eastern side of the Western Platform, although somewhat closer to the margin with the Central Graben and c.125 km southeast of 21/26-1D. Unlike that well however, microfaunal assemblages in the post-chalk Palaeogene show more affinity with the "classic" development of Palaeogene biofacies of the Central Graben. The "*Rhabdammina* biofacies" of agglutinated taxa is better (though not completely) developed and the pyritised diatom fauna of the Moray Group (Balder & Sele Formations) is relatively well developed. Possible reworking of some older Palaeocene taxa (e.g. *M.pseudobulloides*) may also have occurred at this level.

The presence of abundant planktonic foraminifera throughout the Late Palaeocene and Earliest Eocene still gives rise to some question regarding the apparent absence of calcareous benthonic taxa. Even if the planktonics are reworked, their re-preservation should not be possible where the "*Rhabdammina* biofacies" is developed as current theory (see Chapter 2) indicates that bottom water (and below sediment surface) chemistry is not conducive to the preservation of calcareous-walled organisms. If the planktonic tests have survived re-burial, there does not appear to be any reason why calcareous benthonic taxa, existing at the time, should not have been preserved also. It is of course possible that crystalline alteration of the ?Cretaceous planktonic tests during their initial process of taphonomy has, in some way, increased their resistance to post-reburial dissolution. However, an examination of this hypothesis does not lie within the scope of this study.

9.9.Well 44/2-1

Microfaunal recovery from this well was moderate to good in the Tertiary interval, becoming very good in the Cretaceous. Intervals were delineated as follows:

2730' - 2760': EARLY? EOCENE, ?YPRESIAN, UNZONED (top not seen)

No age diagnostic taxa were recovered from the single sample within this interval although the overall aspect of the impoverished assemblage, together with its stratigraphic position suggests an ?Early Eocene age. Taxa present in this interval include moderately common

Cibicides ex gr. *dutemplei* and *Lenticulina* spp., together with rare *Cibicidoides truncanus, Reticulophragmium* aff. *amplectens, Ammodiscus peruvianus* and *Cribrostomoides scitulus.*

2760' - 2820': EARLY EOCENE, YPRESIAN, SUBZONES NSP5b and NSP5a

The highest occurrence of (rare) *Subbotina* ex gr. *linaperta* at 2760' suggests the penetration of the Early Eocene, Subzone NSP5b at that depth. An increase in abundance of the same taxon was noted in the subsequent sample analysed at 2790' which would suggest the presence of Subzone NSP5a. The presence of *Vaginulinopsis* aff. *decorata* and *Bulimina aksuatica* also at 2790' are consistent with the age assigned.

2820' - 2850': EARLIEST EOCENE - LATE? PALAEOCENE, YPRESIAN - ?THANETIAN, ZONE NSP4 - ?NSP3

The highest occurrence of *Coscinodiscus* sp.*1* at 2820' indicates an age no younger than earliest Eocene, Zone NSP4 at that depth. This record corresponds to Bioevent M7 of Mudge & Copestake (1992) which is characteristic of the Balder Formation. This taxon occurs in an impoverished assemblage similar in overall composition to those in the intervals above.

2850' - 2990' (log): LATE PALAEOCENE, THANETIAN, ZONES NSP2/NSB1/NSA1

The highest occurrences of the following taxa at 2850', indicate an age essentially no younger than Late Palaeocene - *Bulimina trigonalis* (NSB1), *Spiroplectammina spectabilis* (NSA1) and common *Cenodiscus* spp. (NSP2). The latter record (common *Cenodiscus* spp.) appears to correspond to Bioevent M3 of Mudge & Copestake (1992) which provides a useful guide to the top of the Maureen Formation. However, the presence of *S.spectabilis* is normally associated with the Lista Formation.

The lowest occurrence of *Bulimina midwayensis* occurs at 2940' which, if *in situ*, would indicate an age no older than the Late Palaeocene, Subzone NSB1b at that depth. The base of this Subzone (defined by King, 1989, by the base of *B.midwayensis*) coincides with the Late - Early (Thanetian - Danian) Palaeocene boundary according to King, 1989.

Caved taxa are common throughout this interval However, taxa interpreted as *in situ* also occurring within this interval are mainly representative of the "*Rhabdammina* biofacies" and include *Guembelitria* spp., *Cibicides* spp., *Ammodiscus cretaceus, A.peruvianus, Reticulophragmium amplectens, R.rotundidorsata, Glomospira irregularis, G.charoides,*

G.gordialis, Haplophragmoides spp., *Praecystammina globigerinaeformis, Karreriella conversa* and *Recurvoides* ex gr. *walteri*.

Other taxa occurring within this interval are interpreted as reworked in view of subsequent biostratigraphic and wireline log evidence; e.g. *Bolivinoides incrassata, Gavelinella* ex gr. *voltziana* and *Matanzia varians*, all recorded at 2850'. Also, a major wireline log break occurs at c.2990' (log) which indicates the junction between the Chalk Group and overlying Montrose Group at that depth. However, a sample above that depth (at 2970') contains abundant Late Cretaceous microfossils and is very similar in composition to the remaining (Late Cretaceous) samples analysed from this well. Reworking of Danian or, as in this case, Late Cretaceous microfossils into younger sediments (Maureen Formation and equivalents) is not unknown form the North Sea (Mears, *pers comm.*).

The absence of common pyritised diatoms of the genus *Coscinodiscus* (characteristic of Zone NSP4) would appear to suggest that most of Zone NSP4 may be missing. However, this may be due to the location of the well being well towards the southernmost limit of these organisms during the Late Palaeocene. This Zone (and its NSB and NSA equivalents) is also characterised by a lack of calcareous or agglutinated foraminifera which is difficult to observe in this well due to the effects of caving. A hiatus between this and the overlying interval is therefore tentatively suggested.

An additional "anomaly" within this interval concerns a wireline log signature at c.2850' which shows a relatively prominent gamma spike, below which for c.40' is a "bulge" pattern. This signature is very similar to that shown by the Balder Formation elsewhere in the North Sea Basin and this study area (see well 29/25-1) although the age of this interval is somewhat at variance with that interpretation. This, together with the apparent large amount of reworking of Late Cretaceous microfossils into the base of this interval suggests the unlikely, though possible theory, that measured ("driller's") depth and actual ("logger's") depth are out of synchroneity over this part of the well. The samples defining the top of the overlying interval (2820') and the sample at the base of this interval interpreted as reworked (2970') would stratigraphically "fit-in" with the available wireline log data if they were both transposed down the well by c.30'. Thirty feet is the approximate length of a single length of drill-pipe and, as such, can sometimes be inadvertently omitted from the overall tally of perhaps hundreds of drill-pipe lengths that go to calculate the total measured ("driller's") depth of a well. This is an albeit very rare occurrence but has been witnessed elsewhere by the author at first hand. However, the circumstances that were occurring during the drilling of this well cannot be reproduced and this theory has to be a matter of conjecture. Consequently, the biostratigraphic interpretation stands as described herein.

2990' (log) - 3090': LATE CRETACEOUS, LATE - ?EARLY MAASTRICHTIAN, ZONES FCS23 - ?FCS22

The top of this interval is marked by the abrupt wireline log break (reduction in gamma and increase in sonic velocities) at 2990' (log) which is indicative of the penetration of the Chalk Group at that depth. The subsequent sample analysed at 3000' indicates a Late Cretaceous age for the Chalk Group which suggests that the topmost Formation of the Chalk Group, (Ekofisk Formation of Early Palaeocene (Danian) age) is missing in this well.

The highest *in situ* occurrence (notwithstanding the comments on reworking - see interval above) of *Bolivinoides draco* at 3000', together with *Heterohelix* spp., *Globigerinelloides praerihillensis, Rugoglobigerina* spp. and *Praebulimina laevis*, all indicate an age no younger than the late Maastrichtian, Zone FCS23. *B.draco* itself is restricted to the later part of this Zone. The occurrence of *Bolivinoides miliaris* in the lowest sample examined at 3090' may suggest the presence of sediments of early Maastrichtian age (Zone FCS22) at that depth. According to King *et al*., 1989, this species does not range above the early Maastrichtian in the Southern North Sea.

Other taxa, in addition to those described above, which occur within this interval include *Rugoglobigerina rugosa, Globotruncanella havanensis, Gavelinella* spp. (mainly *G.* ex gr. *voltziana* and *G.beccariiformis*), *Stilostomella pseudoscripta* and *Gyroidinoides nitidus*. They are all consistent with the stratigraphic age assigned to the interval.

ADDITIONAL COMMENTS:

This well lies within the northern part of the Silver Pit Basin and is separated from the Central Graben and Dutch Central Graben by the Cleaver Bank High and Mid-North Sea High to the east and northeast. It lies c.150 km south of well 29/25-1 and c.160 km north of the remaining study wells grouped mainly towards the south of Quadrant 49.

Although not situated in the typical areas of Palaeocene deposition (i.e. Central / Viking Graben and Outer Moray Firth) this well nevertheless displays a reasonable "*Rhabdammina* biofacies" of agglutinated taxa typical of those more "classic" areas. Also, "typical" Maureen and Sele/Balder microfaunas are likewise observed (reworked Late Cretaceous taxa above the chalk and suites of pyritised diatoms respectively). It appears therefore, that the area encompassed by the Silver Pit Basin may well have been an active Palaeocene depocentre for the "deeper water" clastics as characterised by the Maureen, Lista, Sele and Balder Formations further to the north and northeast, although separated from them by the

Mid-North Sea High. The area may have appeared as a kind of "embayment" towards the south and southwest of the main Palaeocene North Sea depositional area.

9.10.Well 49/10-1

Microfaunal recovery from this well was good and consisted of abundant planktonic, calcareous benthonic and agglutinated foraminifera, together with common diatoms. Relatively large amounts of caved taxa, both from within the interval analysed and from younger sediments, were also recorded and poor hole conditions can be seen reflected in the rather erratic calliper log trace shown over this interval. Intervals were delineated as follows:

2820' - 2860' (log): EARLY EOCENE, YPRESIAN, ZONES NSP5 / NSB 3 / NSA 4-3 (top not seen)

The two samples analysed from this interval yielded abundant and diverse microfaunal assemblages containing characteristic Early Eocene taxa. The highest occurrence of abundant *Globanomalina* spp. (*G.wilcoxensis* and *G.micra*) indicate an age no younger than Middle Eocene, Lutetian, Zone NSP 7 at 2820', although the occurrence of moderately common *Subbotina* ex gr. *linaperta* in the subsequent sample at 2830' would appear to suggest a slightly older age for this interval i.e. Early Eocene, Zone NSP 5 with the *Globanomalina* spp. possibly caved from unsampled intervals above. The highest occurrences of *Turrilina brevispira* at 2820' and *Bulimina* sp. nov. *sensu* King (1983) (= *Bulimina* sp.A of King, 1989) at 2830' provides supporting evidence for this age assignment. These species is restricted to (mainly) the upper part of Zone NSB 3. The highest occurrences (at 2830') of the agglutinated taxa *Spiroplectammina navarroana* and *Reticulophragmium amplectens* lend additional support for an Early Eocene age for this interval. Both taxa range throughout Zones NSA 4 and 3 which are of earliest Middle - Early Eocene age. In addition to those taxa mentioned above, the following species were also recorded within this interval - *Globigerina officinalis* (caved), *Catapsydrax* spp., *Acarinina bullbrooki* "group", *Acarinina soldadoensis* "group" (probably *Acarinina pentacamerata*), *Nodosaria* spp., *Cibicides* ex gr. *dutemplei* (caved), *Angulogerina germanica* (caved), *Bulimina trigonalis, ?Cibicidoides succedens, Planulina palmerae, Rhizammina indivisa, Karreriella conversa, Bathysiphon discreta* and *Cribrostomoides* spp., together with other rare caved taxa.

2860' (log) - ?2900' (log): EARLIEST EOCENE - ?LATEST PALAEOCENE, YPRESIAN - THANETIAN, ZONE NSP 4

A wireline log break (relatively high gamma peak) is taken to represent the top of the Balder formation at 2860' (log). The subsequent sample analysed (2870') yielded rare pyritised diatoms which become even more common at 2880' and include the highest occurrence of *Coscinodiscus* sp.*1*. This is indicative of an earliest Eocene - latest Palaeocene, Zone NSP 4 age at that depth and corresponds to Bioevent M7 of Mudge & Copestake (1992). The remainder of the microfaunal assemblages appear to contain abundant caved taxa which continue to be abundant throughout samples analysed down the well. Consequently, it is not possible to reliably pick certain other Zones which are based on downhole disappearances of taxa and/or barren intervals. However, another log break (reduction in gamma ray and stability of hole conditions) at 2900' may tentatively indicate the junction between the Balder Formation and the older pre-Balder interval below.

?2900' (log) - 3003' (log): LATE PALAEOCENE, THANETIAN, ZONE NSA 1

Microfaunal assemblages throughout this interval contain abundant caved taxa, plus other elements that may be regarded as *in situ* although are of only general age diagnostic value.

Agglutinated foraminifera are abundant throughout this interval and those above. However, the distribution chart shows that a subtle increase in numbers and diversity occurs around 2920' near the top of this interval and suggests the presence of Zone NSA 1. This may correspond to Bioevents M5/4 of Mudge & Copestake (1992) which occur near or at the top of the Late Palaeocene Lista Formation. A decrease in recovery and diversity of *in situ* calcareous benthonic and planktonic taxa can also be observed at the same level.

These assemblages, although containing no Late Palaeocene restricted taxa (e.g. *S.spectabilis*), include in addition to those agglutinated taxa from higher intervals mentioned above, *Glomospira charoides, G.gordialis, G.irregularis, Thurammina* spp., *Ammodiscus cretaceus, A.peruvianus, Praecystammina globigerinaeformis, Haplophragmoides / Cyclammina* spp., *Cribrostomoides scitulus, Trochammina* spp., and *Recurvoides* spp. Although ranging higher, these species are consistent with the Late Palaeocene interval age assigned and possible represent Zone NSA 1.

Of the calcareous benthonic taxa, the only taxon of possible stratigraphic value recorded as *in situ* is *Bulimina trigonalis*, positively identified at 2970'. The range of *B.trigonalis* is sporadic but appears to be bimodal (King, 1989) ranging within the upper part of Zone NSB2 (Balder Formation equivalent) and through most of the underlying Subzone NSB 1c (wholly Late Palaeocene). However, in this well, specimens bearing affinity to *B.trigonalis* have been recorded in the Early Eocene interval above (NSB 3). Specimens questionably identified as *B.trigonalis* have been recorded at and below 2880' and possible correspond to the upper range of King, 1989.

No Late Palaeocene restricted planktonic foraminifera were recovered from this interval although caved taxa are abundant. However, *Subbotina triangularis*, though ranging into the interval above, can be found in strata of Late Palaeocene - Eocene age worldwide and is recorded at 2910' and below within this interval.

3003' (log) - 3030': EARLY PALAEOCENE - ?LATE CRETACEOUS, DANIAN - ?MAASTRICHTIAN, ZONES NSP 1 - ?FCS 23

A wireline break (reduction in gamma ray and change in sonic character) marks the junction between the Montrose and Chalk Groups at 3003' (log). Microfaunal assemblages analysed from this interval are dominated by caved taxa. However, those rarer taxa interpreted as *in situ* include significant planktonic species such as *Globorotalia ?haunsbergensis* (3010'), *G.?plannocompressa* (3030'), *Planorotalites compressa* (3030') and *Eoglobigerina trivialis* "group" (3030'). These taxa, though known to range slightly higher, are characteristic of the Early Palaeocene, Danian, particularly where recorded from limestones attributed to the Chalk Group. If *in situ*, these taxa would indicate the presence of the Ekofisk Formation (Danian age equivalent) at the top of the Chalk Group within this well. However, the lowest two samples analysed (3020' and 3030') yielded rare calcareous benthonic foraminifera suggestive of a Late Cretaceous age. These include *Cibicides ?beaumontiamus* (3020'), *?Praebulimina* spp. (3030') and *Quadrimorphina* spp. (3030'). However, a change in wireline log character is also noted at 3037'; i.e. below the lowest sample examined. This may very tentatively be taken to mark the possible junction between the Danian Ekofisk and the Maastrichtian Tor Formations in this well. Limestones above this depth are also marly and therefore more characteristic of the Ekofisk Formation and distinct from the "cleaner" Tor Formation. Consequently, the occurrence of these taxa may be due to reworking and therefore the presence of sediments of Late Cretaceous age in this interval is questioned.

ADDITIONAL COMMENTS:

This well lies within a structural depression on the Cleaver Bank High, some 125 km south-southeast of well 44/2-1 but only 25-30 km north of the group of remaining study wells in the south of Quadrant 49. It is the most southern well of those studied to display a fairly representative "*Rhabdammina* biofacies" of agglutinated taxa in the Late Palaeocene, together with pyritised diatom suites characteristic of the Balder/Sele Formations and, to a lesser extent, Maureen Formation assemblages (e.g. reworked Cretaceous taxa and downhole incoming of typical Early Palaeocene planktonic forams above the Chalk Group).

Although situated on a structural high (or depression within it), palaeodepths during the Late Palaeocene particularly, must have been sufficiently great to allow the establishment of a "*Rhabdammina* biofacies". This depression may have allowed the marine connection between the Silver Pit "embayment" described above, and the main Palaeocene North Sea depocentres in the north around the southern part of the Cleaver Bank High and thence via the Dutch Central Graben.

9.11.Well 49/20-2

Microfaunal recovery from this well was poor with even the most productive samples yielding fewer than thirty specimens. Wireline log traces are also indistinct and show little of the characteristic signature patterns normally associated with distinctive wireline markers such as the Balder Formation of the top of the Chalk Group. Intervals were delineated as follows:

2490' - 2610': EARLY EOCENE - ?LATE PALAEOCENE, UNZONED (top not seen)

Impoverished assemblages from this interval make interpretation difficult. However, an Early Eocene age appears more likely in view of the biostratigraphic data from the interval below.

The highest occurrence of *Bulimina trigonalis*, if *in situ*, provides possible evidence for a Late Palaeocene age in the highest sample analysed from this interval at 2490'. This species is restricted to the Late Palaeocene, Subzones NSB 1b-c, although may rage higher (see above and below). Some support for this age may be provided by the highest occurrence of *Globigerina chascanona* at 2520'. This species has been recorded from the uppermost part of the Reculver Silts (Late Thanetian) by Haynes (1956 & 1958) but is also recorded ranging into the London Clay Formation, Unit B (Early Eocene) by Murray & Wright, 1974. Other taxa recovered from this interval are also more suggestive of an Early Eocene age (unless caved). They include *Globorotalia danvillensis, Globigerina patagonica* (both at 2520'), *Subbotina* ex gr. *linaperta* (at 2550') and *Globanomalina wilcoxensis* (at 2580').

At 2610': EARLY EOCENE, YPRESIAN, ZONE NSP 4 (lower part).

The occurrence of common non-pyritised diatoms (*Coscinodiscus* sp.20/26 *sensu* G.S.S.) indicates a definite Early Eocene age at 2610'. This event occurs near the base of the NSP4 zone and is fairly consistently recorded some 30 feet vertically below the highest occurrence of the reliable Balder Formation indicator, *Coscinodiscus* sp.1 in many other

North Sea sections. *Coscinodiscus* sp.1 was, however, not recorded in this well. No further specimens of *Coscinodiscus* sp.20/26 were recorded from samples blow 2610'.

This suggests that the upper part of the Balder Formation (or a large part of it) is missing from this well and that consequently a hiatus is placed at the junction between the two intervals.

2640' - 2790': LATE PALAEOCENE, THANETIAN, UNZONED

Assemblages from this interval are very impoverished and contain only caved taxa. However, in view of the age assigned to the interval above, a Late Palaeocene, Thanetian age is envisaged.

A specimen questionably identified as *Cibicidoides succedens* near the base of this interval at 2760', provides some support for this age. This species ranges throughout the Late Palaeocene Subzones NSB 1c-b. Samples throughout this interval were very impoverished consisting mainly of caved taxa, although a species of *Chiloguembelina* spp. was also recorded at 2760' which may be *in situ*.

2790' - 2850': LATE CRETACEOUS, ?MAASTRICHTIAN, ?ZONES FCS 23 - 22 (base not seen)

An increase in microfaunal recovery at 2790' marks the top of this interval. Although also containing some caved taxa, the highest occurrences of *Gavelinella* ex gr. *voltziana, G.pertusa* and *Gyroidinoides nitidus* in this sample indicates penetration of the Late Cretaceous. The occurrences of *Gavelinella bembix* and *Osangularia* spp. at 2820' and a specimen questionably identified as *Angulogavelinella bettenstaedti,* support the general Late Cretaceous age. All these taxa are relatively long ranging but range no higher than the Late Cretaceous. However, the range of *A.bettenstaedti* is largely confined to the Maastrichtian. It therefore appears that the uppermost formation of the Chalk Group of Early Palaeocene age (Ekofisk Formation) is absent from this well.

ADDITIONAL COMMENTS:

This well lies near the southern tip of the Cleaver Bank High, approximately midway between well 49/10-1 (c.30 km to the north) and c.30 km to the north of the group of remaining Quadrant 49 wells.

Poor microfaunal recovery does not allow good stratigraphic interpretation although it appears that this well has more similarities with microfaunas from wells to the south than to those of the north. Agglutinated foraminifera of the "*Rhabdammina* biofacies" typical of the Lista Formation elsewhere in the North Sea are completely absent, as are pyritised diatom suites characteristic of the (mainly upper) Balder Formation.

9.12. Well 49/24-2

Microfaunal recovery from this well was very good although samples contained abundant caved material. *In situ* recovery was relatively poor. The assemblages are dominated by planktonic foraminifera together with abundant calcareous benthonic foraminifera. All other components are comparatively very rare. Wireline log data from this well is also of value.

1860' - 1955' (log): EARLY EOCENE, YPRESIAN, ZONES NSP 7?-5 / NSB 3 (top not seen)

Samples from this interval contain abundant planktonic foraminifera including *Globanomalina wilcoxensis*, *G.micra*, *Subbotina triangularis*, *Acarinina wilcoxensis* "group", *Acarinina soldadoensis* "group" (probably *A.pentacamerata*) and *Globigerina chascanona*. All these taxa are characteristic of an age no younger than the early Middle Eocene, Zone NSP 7. However, the highest occurrence of *Subbotina* ex gr. *linaperta* at 1900' restricts the age to no younger than Early Eocene, Zone NSP 5.

Calcareous benthonic foraminifera are comparatively rare although stratigraphically significant taxa are present. The highest occurrences of *Turrilina brevispira* (at 1900'), *Vaginulinopsis decorata* and *V.aff. decorata* (both at 1930') are all characteristic of an Early Eocene, Zone NSB 3 age.

All, these taxa, particularly the planktonic species *Globanomalina wilcoxensis* and *Subbotina* ex gr. *linaperta*, together with undifferentiated caved Oligo-Miocene *Globigerina* spp. occur in significant numbers both within this, and caved down into older intervals. Also, the calcareous benthonic fauna throughout this and subsequent intervals, though subordinate to the plankton, is dominated by the distinctive Oligo-Miocene species *Siphonina reticulata*, which confirms the caving problem noted in this well.

1955' (log) - ?1985' (log): EARLIEST EOCENE - LATEST PALAEOCENE, YPRESIAN - THANETIAN, ?ZONE NSP 4.

A wireline log motif (high gamma peak) at 1955' is characteristic of the top of the Balder Formation at that depth. Somewhat tentative support for a corresponding Zone NSP 4 age assignment is provided by the occurrence of rare pyritised diatoms at 1960' and by a specimen of *Coscinodiscus* sp.*1* caved at 1990'. Diatoms, mainly of the genus *Coscinodiscus*, often occur within the Balder and Sele Formations of the Central and Northern North Sea (Bioevents M7 and M6 of Mudge & Copestake, 1992) although their occurrence in the Southern North Sea is less certain due to lack of published research on Tertiary strata from this area. The base of this Formation is very tentatively picked at approximately 1985', based on the bottom of the gamma log motif displaying a characteristic Balder Formation "bulge" pattern.

1985'? (log) - 2219' (log): LATE PALAEOCENE, THANETIAN, SUBZONES NSB1c-b / ?NSP 1c (in lower part).

Samples analysed from this interval yielded abundant caved taxa with rare *in situ* elements. The top of this interval is based on a log pick defining the base of the overlying interval (see above). However, the single occurrence of *Bulimina midwayensis* provides evidence for an age no younger than Late Palaeocene, Subzones NSB 1c-b, at 1990', just below the log break. *Bulimina trigonalis* is rare, though more consistently present throughout most of this interval although, somewhat unusually, has been recorded in the sample at 1930' from the Early Eocene interval above. This species, according to King, 1989, ranges only throughout Subzones NSB 1c-b within the Late Palaeocene. Other benthonic taxa recorded which are consistent with a Late Palaeocene age includes *Alabamina obtusa* (highest occurrence at 1960' - i.e. the interval above). This species is often found within Palaeocene "Midway type" faunas according to Berggren & Aubert, 1975. However, it has also been recorded as ranging from the Late Palaeocene - Early Eocene of northern European onshore sections (Murray *et al.*, 1989).

The planktonic assemblages, though dominated by caved taxa, yielded rare but highly significant forms. Specimens questionably assigned to *Morozovella uncinata* (highest occurrence at 1990') and *Morozovella praecursoria* (highest occurrence at 2050') may indicate the presence of sediments that could be assigned to the global planktonic foraminiferal Zones P2-P3 of Blow (1969 & 1979). These two Zones straddle the Late - Early Palaeocene boundary - within P2 according to Blow (1969) or at the top of P2 according to Berggren (1971) (see Chapter 7.2.1 for discussion). These taxa are significant in that they may represent the presence of a post-Danian (albeit for only a short period) planktonic fauna which may have existed in some parts of the Southern North Sea whilst their preservation in other areas was inhibited due to adverse physico-chemical conditions

at or below the sediment-water interface. The part of this interval containing these taxa (2050' - 2219' log) may be in some part equivalent to Subzone NSP 1c of King, 1989, which occurs in the lowermost part of the Late Palaeocene and whose top is based on the downhole reappearance of planktonic foraminifera below Late Palaeocene intervals barren of such forms.

Below the lowest recorded occurrences of these planktonic taxa, although still within this stratigraphic interval, a wireline log break, consisting of a shift to higher gamma values, occurs at c.2095' (log). This would appear to reflect a downhole change to more argillaceous lithologies. Although evidence is not conclusive, the three samples analysed below this log break and above the interval below, yielded fewer specimens, most of which are caved, with the lowest sample (2180') completely barren of microfauna. This may (very tentatively) suggest a downhole decline (?reduced palaeodepth) in conditions suitable for foraminiferal existence.

2219' (log) - 2220': EARLY PALAEOCENE, DANIAN, ZONES NSP 1 / NSB 1a (base not seen)

A wireline log break (abrupt decrease in gamma values) marks the top of this interval at 2219' and corresponds to the penetration of the Chalk Group at that depth. The single sample analysed from this interval (2220') yielded moderately common planktonic foraminifera, *Globoconusa daubjergensis* and *Morozovella pseudobulloides*, indicative of the early Palaeocene Zone NSP 1. The former species partly defines the M1 Bioevent of Mudge & Copestake (1992) and marks the top of the Ekofisk Formation. The benthonic taxon *Tappanina selmensis*, also recovered from the same sample, is also characteristic of the Early Palaeocene Subzone NSB 1a.

ADDITIONAL COMMENTS:

Results from this well are of particular interest as a comparison to the results of Crittenden who studied the planktonic foraminifera from this well as part of an unpublished M.Sc. study in 1979, the results of which were subsequently published (Crittenden, 1981 and 1982) and discussed further (Crittenden, 1986). He recognised a total of 72 species from c.2500 specimens with individuals, as in this study, dominated by *Pseudohastigerina* spp. (*Globanomalina* spp. herein). Crittenden also noted extensive caving and the majority of the species identified by him range from levels stratigraphically higher than the Palaeocene - Early Eocene. Crittenden used the zonation scheme of Stainforth *et al.* (1975 - see chapter 7.2.1) and gives the following ages for the samples he examined:

1300'-1340': Early Eocene, *G. formosa formosa - G. aragonensis* Zones
1460'-1500': Early Eocene, *G. subbotinae* Zone
1620'-1660': Late Palaeocene/Early Eocene, *G. velascoensis - G. subbotinae* Zones
1780'-1820': Late Palaeocene/Early Eocene, *G. velascoensis - G. subbotinae* Zones
1900'-1930': Late Palaeocene - Early Eocene, *G. pseudomenardii - G. subbotinae/G. formosa formosa* Zones
1930'-1960': Middle - Late Palaeocene, *G. pusilla pusilla - G. velascoensis* Zones
1960'-1990': Late Palaeocene, *G. velascoensis* Zone
1990'-2020': Middle Palaeocene, *G. angulata - G. pusilla pusilla* Zones
2020'-2050': Middle Palaeocene, *G. uncinata/ G. angulata* Zones
2050'-2080': Middle Palaeocene, *G. uncinata/G. angulata* Zones
2080'-2110': Early - Middle Palaeocene, *G. pseudobulloides - G. uncinata* Zones
2110'-2140': Early - Middle Palaeocene, *G. pseudobulloides - G. uncinata* Zones
2140'-2180': Early - Middle Palaeocene, *G. pseudobulloides - G. uncinata/G. angulata* Zones
2180'-2220': Early - Middle Palaeocene, *G. pseudobulloides - G. uncinata/G. angulata* Zones
2220'-2260': Late Cretaceous - Early Palaeocene, no younger than *G. pseudobulloides* Zone
2260'-2300': Late Cretaceous, no zone assigned.

This breakdown is in broad agreement with that of the present author however in the present study, the sample at 2220' was the lowest sample analysed from this well and thus the position of the Cretaceous - Tertiary boundary cannot be confirmed although it seems acceptable according to Crittenden's data. Crittenden's "Middle" Palaeocene (= lower part of the Late Palaeocene in North Sea terminology) is based on the occurrence of *Globorotalia (=Morozovella) uncinata* and *Globorotalia (=Morozovella) angulata*, the latter species unfortunately not illustrated or discussed taxonomically. The occurrence of *G. uncinata* was questioned by King (1983) as was the Danian microfauna as a whole. King stated that no Danian chalks were recorded in this well although, according to Crittenden (1986), the sample at 2220'-2260' is stated as "clearly" having a chalk component (of c. 45%). This is recorded as the first downhole appearance of chalk lithologies in this well, a fact which appears to be corroborated by the wellsite geologist's "mud-log" (*pers. comm.* from Shell U.K. to Crittenden, 1986). The wireline log trace clearly shows the penetration of the Chalk Group at c.2219' (log) i.e. within the depth-range encompassed by the sample at 2220'.

The present author regards the record of *G. uncinata* by Crittenden as confirmed as rare specimens of this taxon have been recovered in this study from this well. Unfortunately, Crittenden's record of *G. ("cf.") angulata* (1979, 1981) cannot be proven as his specimen

has not been illustrated, a fact which Crittenden himself admits (1986). This matter, however, does raise the question as to the extent to which *living* post-Danian angulo-conical and/or keeled globorotaliids were able, if at all, to penetrate into the North Sea area during the remainder of the Palaeocene. It is generally accepted (see Chapter 2) that angulo-conical / keeled planktonic species are not present in and around the North Sea Basin, mainly due to adverse palaeoecological conditions (low temperatures and water depths). However, it is not beyond possibility that rare specimens may have been introduced into the area as a result of wind or current action, or as a result of brief periods where conditions may have been acceptable to more "opportunistic" representatives of the species. Planktonic taxa however, do not live for long periods and for individuals to exist in these environments, they would have to be washed in during the surface-dwelling phase in the early part of their life cycle as juveniles. A possible nearby source for a "pool" of thriving representatives of *G. angulata* may have been the North Atlantic, where specimens of *G. angulata* have been recorded in boreholes in the West Shetlands Basin and the Faeroe Basin (cited without sources in Crittenden, 1986). Dead, empty tests may also be transported by current action prior to deposition although this would not appear likely in the above scenario given the distances and current directions prevalent at the time.

G. angulata has also been recorded from several onshore localities around the North Sea area. Hooyberghs (1983) records the species in the Calcarenite of the Mechelen aan de Maas borehole of Belgium within Zone P3 at 290.5m. Pozaryska & Szczechura (1976) record a single specimen from the Svedala borehole in Skane and Hansen (in Pozaryska & Szczechura, 1976) records a specimen from Denmark. El-Nagger (1967, 1969) records the species from the Tuffeau de Lincent in the *G. velascoensis* Zone and also from the Givry 318 well in Belgium. King (in a *pers. comm.* to Crittenden, 1986) regards El-Nagger's specimens as misidentified however.

G. angulata is 4-5 chambered plano-convex taxon which is clearly "angulo-conical" in its aspect with the periphery of all chambers being subangular to subrounded in shape. Although spines are concentrated around the periphery, they do not form a true keel (see Stainforth *et al.*, 1975 fig. 34). It evolved from *Globorotalia (=Morozovella) pseudobulloides* via *G. uncinata*. *G. uncinata* is similar although later chambers in the final whorl (of which there are slightly more than *G. angulata*: 5-6) lack the more angular periphery and are, instead, more rounded and globular, particularly the final chamber.

Related species include *Globorotalia trinidadensis* which has the same characteristic recurved spiral side sutures are the above two, although all chambers in the final whorl are globular or pear shaped and display no angular features. *Globorotalia (=Morozovella) praecursoria* appears to be a combination of all three previous morphologies with 5-8 chambers of which the first 2 or 3 are distinctly angulo-conical with subsequent chambers

becoming broadly rounded. Spiral side sutures are initially recurved then become more radial. It has more chambers than *G. uncinata* and *G. angulata*, has more angular initial chambers than *G. trinidadensis* and has less angular final chambers than *G. angulata*.

In regional context, this well lies within a group of 4 wells towards the south of Quadrant 49 in blocks 24 and 25 on a platform known as the Inde Shelf. This group forms the southernmost wells studied herein, though approximately 230 km north-northeast of the onshore UK localities in Kent.

Poor recovery from the 49/24-2 well hinders certain interpretation, although recorded microfaunas appear to have more affinity with the onshore UK and Danish Palaeocene assemblages (i.e. dominated by calcareous benthonic foraminifera) than with those from wells to the north of this area. This indicates that, for the UK side of the area, the southern reaches of the North Sea (i.e. south of the Silver Pit Basin / Cleaver Bank High) did not develop the "typical" depositional style of the "classic" Early Palaeogene hydrocarbon province to the north in the Central / Viking Graben and Outer Moray Firth.

9.13.Well 49/24-3

Microfaunal recovery from this well was good with specimens recovered dominated by planktonic foraminifera of which *Globanomalina* spp. was the dominant genus. However, recovery of good *in situ* and age-diagnostic taxa from this well was poor, with a great many caved specimens evident.

Wireline log data (gamma ray) from this well is also inconclusive. Therefore the stratigraphical breakdown of this well is tentative.

1700' - 1760': EARLY EOCENE - ?LATE PALAEOCENE, YPRESIAN - ?THANETIAN, NSA 3 ZONE (top not seen)

The stratigraphical age of this interval is difficult to interpret. The majority of species recorded would, at face value, be taken to indicate an Early Eocene, Ypresian age. The occurrence of *Gaudryina hiltermanni* (at 1700') would indicate an age no younger than zone NSA3. The abundant planktonic foraminifera are dominated by good Eocene indicators which range through this interval (and below) such as *Globanomalina* spp., *Acarinina wilcoxensis* "group", *Subbotina triangularis* (which may indicate a NSP5a subzone age) and *Globigerina chascanona*. *Subbotina linaperta* "group" also occur (rarely) in this interval (highest occurrence at 1720').

Of the calcareous benthos, *Alabamina obtusa, Bulimina aksuatica* and various cibicidiids (i.e. *Cibicidoides pachyderma* and *Cibicides tenellus*) would support an Early Eocene age.

However, the highest occurrence of *Bulimina trigonalis* (at 1700') may suggest an age essentially no younger than the Late Palaeocene for this interval. Published ranges for this taxon (e.g. King, 1989; Murray *et al.* (as *B.thanetensis*), 1989) restrict its distribution to the Late Palaeocene. However, this species has also been recorded (albeit sporadically or questionably) from younger (i.e. Early Eocene) strata in other wells in Quadrant 49 in this study. This would appear to suggest an upwards range-extension for this taxon in the southern part of the North Sea Basin.

No evidence for the presence of the Balder and Sele Formations of latest Palaeocene - earliest Eocene age was forthcoming. These formations, particularly further north in the Central and Northern North Sea are characterised by a pyritised diatom flora. Their apparent absence in this part of the North Sea may however, be related to environmental effects.

In conclusion, an Early Eocene age is favoured for this interval although the older (Late Palaeocene) age cannot be completely discounted.

1760' - 1780': EARLY PALAEOCENE (DANIAN) - ?LATE CRETACEOUS (3?MAASTRICHTIAN), NSP1a-b SUBZONES

The single sample analysed from this interval at 1760', yielded an assemblage dominated by (mainly caved) planktonic foraminifera. The occurrence of chalk-preserved planktonic foraminifera including *Morozovella pseudobulloides* and small globigerinids (*Globigerina* spp./ *Eoglobigerina* spp. undifferentiated) would suggest penetration of the Chalk Group, Ekofisk Formation (Danian) by this depth. Specimens questionably assigned to *Globoconusa daubjergensis* would also indicate a Danian (particularly early Danian) age. A specimen, also at 1760', assigned to the *Globorotalia eugubina / Globigerina fringa* "group" herein would, if identification is confirmed, refine the assigned age further to earliest Danian, Pa Zone of Blow, 1979 (lower part of subzone NSP1a of King, 1989).

No evidence for the Late - Early Palaeocene Maureen Formation was recorded. This formation is characterised by abundant radiolaria and characteristic planktonic foraminiferal genera, none of which were noted in the assemblages studied.

Rare Late Cretaceous foraminifera (*Globigerinelloides praerihillensis, Praebulimina laevis* and *Cibicides ?beaumontianus*) also recorded at 1760' may be reworked although, if *in situ*, could also indicate the position of the Cretaceous - Tertiary boundary lies between

this depth and the depth of the next uphole sample (i.e. 1740'). However, these taxa are rare in the 1760' sample and better evidence for Late Cretaceous penetration can be found below.

The apparent downhole microfaunal break into chalk-preserved microfaunas, and therefore an indirect indication of Chalk Group lithologies, is not reflected at all on wireline logs over this depth interval. Consequently, an Early Palaeocene, (?earliest) Danian age is favoured for this interval although the possibility of a Late Cretaceous age cannot be excluded. The presence of a major hiatus, with at least most of the Upper Palaeocene missing, is inferred at 1760'.

1780' - 1920': LATE CRETACEOUS (MAASTRICHTIAN) (base not seen)

The highest occurrence of abundant *Heterohelix* spp., together with *Pseudotextularia elegans, Gavelinella ?pertusa, ?Eouvigerina aculeata* and a specimen bearing affinity with *Bolivinoides laevigatus* all indicate the definite penetration of the Late Cretaceous by 1780'. Other Late Cretaceous index taxa recorded include *Bolivinoides draco* (at 1890').
P.elegans is particularly indicative of the late (latest) Maastrichtian in the North Sea area and, together with information from the interval above, may suggest that the Cretaceous - Tertiary boundary in this well is conformable, at least within the limits of resolution employed over a 20' sample gap. Regionally, this situation would be unusual as, to the present author's knowledge, no offshore interval (in the UK sector) has been proven to demonstrate a continuous boundary sequence.

ADDITIONAL COMMENTS:

Like the previous well (49/24-2) poor recovery hinders interpretation for this well. However, microfaunas recorded in this well do show affinities with assemblages from nearby wells and onshore UK and Danish localities. Like 49/24-2, this well lies south of the southern limit of the development of (good) "*Rhabdammina* biofacies", diatom suites and other characteristic Palaeocene bioevents, more typical further to the north. Also, calcareous benthonic assemblages, though reasonably diverse, begin to become dominated by cibicidiid taxa in most samples. Though normal marine conditions are indicated, Palaeocene palaeodepths were relatively shallow, thus preventing the establishment of good planktonic foraminiferal assemblages, particularly the angulo-conical morphotypes of good biostratigraphic utility.

9.14.Well 49/24-4

Microfaunal recovery from this well was moderate to good, with specimens recovered dominated by the planktonic foraminiferal genera *Globanomalina* and *Subbotina*. However, recovery of good Palaeocene age-diagnostic and *in situ* taxa was very poor with the majority of specimens recorded being interpreted as caved.

1460' - 1550': MIDDLE - EARLY EOCENE, LUTETIAN - YPRESIAN, NSP7? - NSP5 / ?NSB4 - NSB3 (top not seen)

This interval is dominated by the planktonic foraminiferal genus *Globanomalina* (Middle - Early Eocene) and the species *Subbotina triangularis* (Early Eocene - Late Palaeocene) which were recorded at and below 1460'. Other taxa diagnostic of the Eocene include *Subbotina linaperta* "group", *Bulimina aksuatica* and *Anomalinoides capitatus*. Other taxa, more characteristic of the Early Eocene include *Bulimina* sp.A (King), *Globigerina chascanona, ?Planorotalites chapmani* and (recorded at 1490'), *Acarinina wilcoxensis* "group".

The records of *Vaginulinopsis decorata, V.decorata* subsp.A (King), *Gaudryina hiltermanni* and *Turrilina brevispira* (all at and below 1520'), support the overall age interpretation.

1550' - 1700': EARLY EOCENE - ?LATE PALAEOCENE, YPRESIAN - ?THANETIAN, UNZONED

The highest occurrence of very common *Acarinina soldadoensis* "group" at 1550', indicates the penetration of an interval no younger than the Early Eocene but possibly as old as Late Palaeocene. However, no Late Palaeocene-restricted taxa were recorded, therefore although an early Eocene age is favoured for this interval, the older (Late Palaeocene) age cannot be completely discounted.

The highest occurrence of *Spiroplectammina navarroana* is recorded at 1670'. This species, whilst being more characteristic of the Early Eocene, can range down into the Palaeocene.

1700' - 1790': LATE PALAEOCENE, THANETIAN, ZONE NSA1

The top of this interval is marked by a major downhole reduction in microfaunal recovery at and below 1700', although the highest occurrence of *Glomospira charoides* is also noted

at this depth. This observation may correspond to Bioevent M5 of Mudge & Copestake (1992) and indicate penetration of the Late Palaeocene (Lista Formation).

The highest occurrence of *Karreriella conversa* (at 1730') supports this interpretation. The highest occurrence of this species is used to partly define Bioevent M4 (Late Palaeocene, Lista Formation) of Mudge & Copestake (1992).

Samples throughout this interval are extremely impoverished/barren of microfauna and occasionally very rare, reworked Late Cretaceous taxa are seen. No evidence for the presence of the Balder and Sele Formations of latest Palaeocene - earliest Eocene age was forthcoming. These formations, particularly further north in the Central and Northern North Sea are characterised by a pyritised diatom flora. Their apparent absence in this part of the North Sea may be related to environmental effects however.

Similarly, no evidence for the Late - Early Palaeocene Maureen Formation was recorded. This formation is characterised by abundant radiolaria and characteristic planktonic foraminiferal genera, none of which were noted in the assemblages studied.

1790': LATE CRETACEOUS, EARLY MAASTRICHTIAN - CAMPANIAN, FCS 22-10 ZONES (base not seen)

A microfaunal break, marked by the highest downhole occurrences of *Hedbergella* spp., *Heterohelix* spp. and *Globigerinelloides* spp. at 1790', indicate penetration of the Late Cretaceous by that depth. The record of *Eouvigerina aculeata* in the same sample indicates an age within the range Early Maastrichtian - Campanian.

The microfauna recorded at 1790' indicates the penetration of the Chalk Group, Tor / Hod Formations. No biostratigraphic evidence for the presence of the Danian Ekofisk Formation was forthcoming.

ADDITIONAL COMMENTS:

Like other wells studied from Block 49/24 (-2, -3), poor recovery from 49/24-4 hinders interpretation. The poor recovery characterising these three wells, which all lie within 5 km of each other, differs strongly from the excellent recovery of similar assemblages obtained from the nearby 49/25-2 well approximately 15 km to the southeast of this group. This would suggest (assuming the wells were drilled and sampled correctly and consistently) that the poor recovery is a "real", though very local feature of this part of the North Sea and is probably due to palaeoenvironmental factors.

9.15.Well 49/25-2

Microfaunal recovery from this well was good, however contamination by caving is prevalent throughout the interval studied. Samples from this well yielded rich and diverse calcareous benthonic foraminiferal assemblages and subordinate planktonic taxa. Agglutinated foraminifera are relatively scarce and diatoms very rare. Wireline log data from this well were not available and the stratigraphic interpretation based on micropalaeontological evidence only.

2030' - 2050': MIDDLE EOCENE, LUTETIAN, ZONE NSP7 (top not seen)

This interval (which is represented by one sample) is dominated almost exclusively by abundant planktonic foraminifera of the genus *Globanomalina* (specifically *G.wilcoxensis*) indicating an age no younger than Middle Eocene Zone NSP7 at the highest sample examined in this well.

2050' - 2410': EARLY EOCENE, YPRESIAN, ZONE NSP 5

The highest occurrence of *Globigerina chascanona* at 2050' indicates the penetration of the Early Eocene at that depth. The highest occurrence of representatives of the *Acarinina wilcoxensis* group provides further evidence for the assigned age in the subsequent sample at 2080'. Additional confirmation of an Early Eocene age is provided by the highest occurrences of *Spiroplectammina adamsi, Pullenia quinqueloba* and *Pulsiphonina prima,* all at 2140'. None of the taxa listed above range above the Early Eocene.

The downhole reappearance of planktonic taxa below the Middle Eocene allows the upper part of this interval (at and above 2200') to be assigned to the NSP 5b Subzone. The presence of Zone NSP 6 which straddles the Early - Middle Eocene boundary could not be confirmed. This Zone is defined by an influx of the radiolarian genus *Cenosphaera.* No representatives of this genus were recorded, either *in situ* or caved. However, the presence of abundant planktonic foraminifera throughout this interval and the interval above, suggests that conditions in the surface waters were sufficiently "normal" to have allowed the existence of radiolaria. Consequently the junction at this level in the well is considered to be marked by a hiatus which approximately coincides with the Early-Middle Eocene boundary.

The highest downhole occurrence of common *Subbotina linaperta* group defines the top of Subzone NSP 5a at 2200'. The highest occurrences of *Globorotalia reissi, Gaudryina hiltermanni* and *Bulimina trigonalis* in the same sample, together with *Alabamina obtusa* at 2380', support an "early" Early Eocene age for this part of this interval. The abundance

and diversity of planktonic and calcareous benthonic taxa reaches a maximum in this part of the interval.

2410' - 2440': EARLIEST EOCENE - LATEST PALAEOCENE, YPRESIAN - THANETIAN, ZONE NSP 4

The highest occurrence of the pyritised diatom *Coscinodiscus* sp.1, albeit very rare, at 2410' defines the top of Zone NSP 4 which straddles the Eocene - Palaeocene boundary. The presence of *Cancris* sp.A (King) in the same sample provides, if *in situ*, some support for the assigned age as this species is restricted to the Early Eocene.

2440' - 2560': LATE PALAEOCENE, THANETIAN, ZONES NSB 1, NSA 1 & (2530'-2560') NSP 1 (base not seen)

Although the proportion of agglutinated taxa throughout this well is small, a relatively sharp increase in numbers is noted at and below 2440'. This event probably corresponds to Bioevent M5/4 of Mudge & Copestake (1992) which marks the top of the Lista Formation in much of the Central and Northern North Sea and defines Zone NSA 1 of King (1989).

Support for a Late Palaeocene age is provided by the occurrences of *Cibicides susanensis* (in the same sample), ?*Spiroplectammina spectabilis* at 2470', *Gyroidinoides danvillensis* var. *gyroidinoides* and *Morozovella praecursoria* at 2500', *Spiroplectammina thanetana, Globulina ampulla, Lenticulina multiformis* and *Cibicidoides dayi* at 2530' and *Gavelinella danica* at 2560'. These, mainly calcareous benthonic or calcareous agglutinated taxa, define Zone NSB1 within this interval (NSB 1 equates wholly with NSA 1). The lowest recorded downhole occurrence of *Coscinodiscus* spp. occurs at 2470' near the top of this interval. This is consistent with the stratigraphic distribution of this taxon in the North Sea area and further supports a Late Palaeocene age for this interval.

The highest occurrences of the planktonic taxa *Eoglobigerina* spp. and *Morozovella pseudobulloides* at 2530', allows the inclusion of part of the earliest Late Palaeocene planktonic Zone NSP 1 (probably Subzone NSP 1c) at the base of this interval. This event may approximate to Bioevent M2 of Mudge & Copestake (1992) and lies close to, if not directly on, the Early - Late Palaeocene boundary. However, no direct evidence for the confirmed penetration of the Early Palaeocene (Danian) was forthcoming.

A large (c.110') sample-gap separates the base of this interval from the top of the underlying Late Cretaceous interval. This, together with the absence of wireline log data, does not allow the accurate placement of the junction between the Montrose and Chalk

Groups in this well. Nor does it allow the determination of the stratigraphic nature (i.e. unconformable or otherwise) of the Cretaceous - Tertiary boundary in the well.

2670' - 2780': LATE CRETACEOUS, MAASTRICHTIAN - CAMPANIAN, ZONES FCS 20 - 23, (top and base not seen)

Although a large (c.110') sample-gap separates the top of this interval from the base of the interval above, a major microfaunal break is noted at and below 2670'. Recovered specimens are all white (i.e. chalk) preserved and include the Late Cretaceous index taxa *Globigerinelloides praerihillensis, Heterohelix* spp., *Gavelinella voltziana* group, *Gavelinella pertusa, Gavelinella nobilis, Cibicides beaumontianus, Gyroidinoides nitidus, Osangularia navarroana, Praebulimina laevis, Pullenia quaternaria, Bolivina incrassata* (including the subspecies *B.i.gigantea*) and *Bolivinoides draco*. The last three taxa suggest a Maastrichtian age for the interval, however, the occurrence of a specimen questionably assigned to *Bolivinoides laevigatus* may suggest, if *in situ*, the interval in part at least could be as old as Campanian.

ADDITIONAL COMMENTS:

This well, the southernmost in the study area, lies c.15 km to the southeast of a group of three wells in Block 49/24. However, as discussed above, microfaunal assemblages from this well show a marked increase in recovery, richness and diversity compared with the 49/24 wells. However, like the 49/24 wells, the 49/25-2 well does not display Early Palaeogene assemblages characteristic of the "classic" areas of the Central / Viking Graben and Outer Moray Firth. Although a "*Rhabdammina* biofacies" is present, it is completely subordinate to the calcareous benthonic and planktonic foraminiferal assemblages recorded from the well. Also, the style of preservation of some of the agglutinated taxa suggests a calcareous type of cement, rather than the non-calcareous type normally associated with typical "*Rhabdammina* biofacies" representatives.

Assemblages from the 49/25-2 well show relatively good (though not strong) affinity with assemblages recorded from onshore Danish and, especially, UK localities, with a number of taxa recorded at two or more localities.

The 49/25-2 well demonstrates an Early Palaeogene palaeoenvironment of normal marine, well oxygenated conditions, with strong open marine / oceanic influences, particularly during the lower Early Eocene when planktonic richness and diversity reaches a maximum. Palaeodepths during the Late Palaeocene were, however, somewhat shallower.

9.16. Wormingford Mere Borehole

Samples from this borehole (although taken from nominally Palaeogene sediments) yielded reworked Cretaceous taxa with little or no presumed *in situ* elements. One sample in particular (15.70m) yielded abundant reworked Cretaceous (mainly Late but some Early) taxa, as well as rare species from the Jurassic (*Lingulina tenera* group.). Most of the samples containing significant reworked assemblages were taken from the interval designated by the B.G.S. as "Woolwich & Reading Beds".

Very rare specimens of what were questionably assigned to Tertiary species were noted (e.g. *Globoconusa daubjergensis, Morozovella pseudobulloides, Acarinina soldadoensis* grp. and *Chiloguembelina cubensis*). However, poor preservation precluded positive identification and the specimens may in fact be of *Rugoglobigerina* spp., *Hedbergella* spp. and *Heterohelix* spp. which are recorded in abundance in other samples.

The data distribution log shows litho- and chronostratigraphic units as indicated by the B.G.S. Lack of *in situ* data herein does not allow confirmation of that interpretation.

9.17. Pegwell Bay / Reculver

Microfaunal recovery from the samples analysed from the Pegwell Bay and Reculver sections was very variable, ranging from barren/impoverished to rich and diverse assemblages. Abundance and diversity appears to increase upwards through the section.

It is rather difficult to reconcile Haynes' "zonule/faunule" interpretation of the Pegwell Bay/ Reculver sections with the material studied herein, mainly because of physical changes in the cliff section at Pegwell due to construction work. As pointed out in Chapter 3, the section sampled by Haynes at Pegwell Bay in the 1950s was more complete and extensive than that which occurs today. At the time of sampling (1984) only the Bullhead Conglomerate and Stourmouth Clays are exposed, together with probably only the lowermost parts of the Pegwell Marls. The Reculver Silts are preserved in a small cliff section below the main road, behind the foreshore and behind the hoverport buildings.

Haynes' 1981 reinterpretation of his 1950's data uses palaeontological information recorded from samples of the Pegwell Marls and Reculver Silts only (samples P16 - RB19) as he recorded no foraminifera from the Bullhead Conglomerate or Stourmouth Clays (samples P1 - P15). Haynes (1981, fig.12.4) subdivides the section into 7 "faunules" and "subfaunules" (see also Chapter 2):

Section	Lithology	Zone	Characteristic* Taxa	Palaeoenvironment
Reculver	Reculver Silts	4a	*C.cunobelini, C.mariae, T.thanetana, P.hofkeri, A.aberystwythi*	Shallow shelf, shoal, 0-20m, delta front
Pegwell	Reculver Silts	4	as above without *A.aberystwythi*	similar to above, but off delta front
	U.Peg. Marl	3b	*H.pegwellensis, C.cunobelini, C.mariae, T.thanetana*	as below but shoaling
	U.Peg. Marls	3a	Reduced fauna but includes taxa recorded in zonule 3 below	as below but poorly aerated bottom waters
	U.Peg. Marls	3	*B.thanetensis, C.proprius, C.cassivellauni, G.danvillensis s.l., H.pegwellensis*	midshelf (20-100m), quiet conditions, prodelta
	L.Peg. Marls	2	sparse agglutinants	as below w/stagnant bottom waters
	L.Peg. Marls	1	*B.thanetensis, A.obtusa, C.proprius C.succedens, H.pegwell., T.thanetana*	Transit. marine - mid shelf (10-60m) quiet, tendency for lowered O_2 levels

* species comprising >10% of numbers in the assemblages

The present author's sample from the Bullhead Conglomerate (PB3) was (like Haynes's) barren of microfauna. However, microfossils were recovered (albeit mainly in low numbers) from the Stourmouth Clays:

Glomospirella woodi	-	abundant
Chiloguembelina spp.	-	common
Globorotalia perclara	-	common
?*Globorotalia planocompressa*	-	rare (reworked)
Cibicides succedens	-	rare
Anomalinoides nobilis	-	rare
Gyroidinoides danvillensis var. *gyroidinoides*	-	rare
Coscinodiscus cf. species 8 (G.S.S.) (diatom)	-	rare
Coscinodiscus cf. species 16 (G.S.S.) (diatom)	-	rare

G.woodi was recorded in abundance from sample PB8, from which sample was also recorded most of the planktonic foraminifera. Providing all these specimens recorded above are *in situ*, the Stourmouth Clays may have been deposited under rather more marine conditions than had been previously thought (estuarine - see Chapter 2). The local abundance of *G.woodi* suggests that, for a short period at least, bottom waters may have been dysaerobic.

In biostratigraphical terms, *G.danvillensis* var. *gyroidinoides* (recorded in the uppermost sample (PB10) of the Stourmouth Clays) is the only taxon restricted to the Late Palaeocene (see Chapter 8 - systematics). *G.planocompressa*, even if the questionable identification of the poorly preserved specimens recorded here is confirmed, ranges no higher than the early Danian and thus is regarded as reworked into the Stourmouth Clays. Rare Late Cretaceous taxa were also recorded. All other taxa recorded have been variously reported from the Late Palaeocene but can range into the Eocene (*A.nobilis* can range downwards into the Cretaceous also).

The remainder of the beach section at Pegwell Bay (i.e. the Pegwell Marls) yielded only two samples separated by a c.3 metre gap. Of these, the lower sample (PB11) yielded a rich and diverse microfaunal assemblage notably different from the Stourmouth Clay samples below:

Bulimina trigonalis - abundant
Astacolus sp.nov. - abundant
Cibicides succedens - very common
Alabamina obtusa - very common
Glomospirella woodi - common
Anomalinoides nobilis - common
Gyroidinoides danvillensis var.*gyroidinoides* - common
Pullenia quinqueloba - common
Cibicides mariae - common
Ammodiscus cretaceus - rare
Trochammina? volupta - rare
Cibicides cunobelini - rare
Cibicides cantii - rare
Heterolepa pegwellensis - rare
Dentalina glaessneri - rare
Lagena inornata - rare

The upper sample (PB12) contained only rare planktonic taxa (*G.perclara, Chiloguembelina* spp.) plus moderately common reworked undifferentiated Late Cretaceous taxa). Both samples (the second due more to stratigraphical position rather than by faunal content) are assigned to the (Lower?) Pegwell Marls.

The presence of *B.trigonalis* (=*B.thanetensis* of Haynes) in abundance together with very common *C.succedens* and *A.obtusa*, plus the absence of *Spiroplectammina thanetana* (=*Textularia thanetana* of Haynes) and *Cibicides proprius*, suggest that the PB11 sample can be assigned to Faunule 1 (?lower part) of Haynes (1981). *H.pegwellensis* (not recorded by Haynes as being particularly characteristic of the lower part of Faunule 1) was only recorded in very low numbers in this sample.

Assemblages from this part of the section suggest deposition under normal marine shelf conditions, though the relative decrease in proportion of cibicidiids (compared with intervals above) and the abundance of nodosariaceans (*Astacolus*) suggests palaeodepths may have been in the order of 50 metres or so. However, the absence of planktonic taxa is unusual given this interpretation. Haynes (1981) suggests that palaeodepths for the Upper Pegwell marls (not sampled here) could have achieved values of up to 100 metres.

The remaining part of the Pegwell section i.e. the Reculver Silts exposed behind the hoverport, yielded rich and diverse assemblages dominated by *Cibicides* and *Spiroplectammina*:

Spiroplectammina thanetana - abundant
Cibicides mariae - very common
Cibicides cunobelini - very common
Cibicides cantii - very common
Cibicides cassivelauni - very common
Cibicidoides alleni - very common
Cibicides lobatulus - very common
Anomalinoides nobilis - common
Cibicides succedens - common
Gyroidinoides danvillensis var. *gyroidinoides* - common
Bulimina trigonalis - common
Nonion applinae - common
"Nodosaria" latejugata - common
Heterolepa pegwellensis - rare
Lagena inornata - rare
Guttulina problema - rare
Globulina ampulla - rare
Globorotalia perclara - rare (PB13 only)
Chiloguembelina spp. - rare (PB13 only)
Nonion laeve - rare (PB13 only)
Alabamina obtusa - rare (PB16 only)
Hazelina thanetensis (ostracod) - rare (PB16 only)

The faunule assignment of this part of the Pegwell succession is less certain. These samples contain two or more species together which, as indicated previously by Haynes (1981), should not have overlapping stratigraphical ranges. However, Haynes' 1981 range diagram only includes those species occurring in numbers >10% of the overall assemblages and therefore their full stratigraphical ranges may be extendible upwards and downwards. Nevertheless, the domination of the assemblages recorded here by the *Cibicides* species *C.mariae, C.cunobelini* and *C.cantii,* together with abundant *S.thanetana,* indicates that this interval is probably best assigned to Zonule 4.

The domination of the assemblages by *Cibicides* and *Spiroplectammina* suggests deposition under normal marine conditions (salinities c.35‰) although the rarity of

planktonic taxa indicates that palaeodepths were relatively shallow (probably < 20-30 metres). Certain genera (e.g. *Cibicides, Bulimina, Nonion*) are known to be tolerant of slightly brackish conditions, although genera known to be common in brackish environments (e.g. *Protelphidium*) were not recorded in this interval.

The Reculver Silts exposed at Pegwell were probably deposited under shallow normal-marine, well oxygenated waters somewhat off the delta front (see below).

The remaining and highest part of the Thanet Formation (Reculver Silts) in the cliff section at Reculver itself (samples RC23 - RC11) yielded the richest and most diverse assemblages from the onshore UK Palaeocene studied:

Cibicides cunobelini - abundant
Cibicides mariae - abundant
Spiroplectammina thanetana - very common
Cibicides cassivelauni - very common
Cibicides cantii - very common
Epistomina vitrea - very common
Protelphidium hofkeri - common
Asterigerina aberystwythi - common
Hazelina thanetensis (ostracod) - rare
Anomalinoides nobilis - rare
Guttulina problema - rare
Bulimina trigonalis - rare
"Nodosaria" latejugata - rare
Heterolepa pegwellensis - rare
Pullenia quinqueloba - rare
?Pararotalia spp. - rare
?Glandulina laevigata - rare
Globulina ampulla - rare
Sigmomorphina soluta - rare
Cibicidoides alleni - rare
Cibicides succedens - rare
?Pulsiphonina prima - rare
Nonion applinae - rare
Nonion laeve - rare
Nonionella cretacea - rare
?Cyamocytheridea magna (ostracod) - rare
Gyroidinoides danvillensis var. *gyroidinoides* - rare
?Praeglobobulimina ovata - rare
?Subbotina triangularis - rare
Coscinodiscus spp. (diatom) - rare

The occurrences of *C.cunobelini, C.mariae, S.thanetana, P.hofkeri* and *A.aberystwythi* all indicate allocation of this interval to Faunule 4a of Haynes (1981).

The richness and diversity of the assemblages indicates deposition under normal marine conditions (salinities of c.35‰), although the scarcity of *in situ* planktonic foraminifera suggests palaeodepths were quite low, probably less than 20-30 metres. However, certain genera (e.g. *Bulimina, Cibicides, Nonion*) are known to be tolerant of slightly brackish conditions (salinities of 32 - 35‰), whilst *Protelphidium* is common in brackish environments. This tendency towards lowered salinity would be found in a delta front environment, as suggested by Haynes, 1981.

The Reculver Silts exposed at Reculver indicate closer proximity to the delta front than those exposed at Pegwell, assuming that both sections are contemporaneous.

The remaining part of the North Sea Basin Palaeocene succession in the U.K. (sampled at Reculver) is comprised of the Woolwich / Reading Beds which yielded barren or extremely impoverished microfaunal assemblages of little age-diagnostic or palaeoenvironmental value. Those specimens recovered are poorly preserved and may be reworked or introduced by sample contamination.

Overall, the onshore UK Palaeocene exposed in Kent represents an initial transgressive phase (Bullhead Conglomerate - Stourmouth Clays - Pegwell Marls) after a major end-Cretaceous sea-level fall. Water depth reached a probable maximum during deposition of the (Upper) Pegwell Marls before the rate of (deltaic) sediment accumulation exceeded rate of accommodation volume increase and the delta prograded into the basin (Reculver Silts). Further progradation and basin filling resulted in the deposition of the essentially marginal and non marine sediments of the Woolwich and Reading Beds

9.18.Lundsgaards Cliff

Microfaunal recovery from three samples analysed from the Kerteminde Marl at Lundsgaards Cliff was moderate, with moderate to good preservation. Assemblages are dominated by calcareous benthonic taxa and *Gavelinella* (as mainly *G.beccariiformis*) is the dominant genus.

Numbers and diversity appear fairly constant throughout the section with between 75-150 specimens comprising c.17 species recorded in each sample. The overall assemblage is indicative of normal marine deposition, probably at inner - middle neritic palaeodepths given the relative lack of planktonic taxa. Some of the taxa (e.g. *Bulimina trigonalis* and *Cibicidoides succedens*) are thought to be tolerant of reduced oxygen levels (Murray *et al.*, 1989).

The presence of *B. trigonalis*, *Matanzia varians* and *Bulimina midwayensis* all confirm a Late Palaeocene age for this section. *G.beccariiformis* ranges no higher than the Late Palaeocene in NW Europe.

It is difficult to correlate this Danish section with an onshore UK equivalent, i.e. the Thanetian of Pegwell Bay or Reculver. There are few species common to both localities:

Alabamina obtusa
Bulimina trigonalis
Cibicides succedens
Cibicidoides alleni
Dentalina glaessneri
Glandulina laevigata
Guttulina problema
Pullenia quinqueloba

However, these taxa are found throughout both the Pegwell Bay and Reculver sections in the UK. A very tentative correlation might possibly be made with Faunule 1 of Haynes, 1981 (in the Lower Pegwell Marls) based on the relatively high numbers of *B.trigonalis* in that Faunule and in the Lundsgaards Cliff section of the Kerteminde Marl.

9.19.Stevns Klint

Microfaunal recovery from the Stevns Klint section was moderate to good. However, preservation was generally poor. The vast majority of the specimens recovered were of extremely small size (c.0.1mm or less) which also hampered identification in some cases. The Stevns Klint section is arguably one of the most important localities worldwide for the Cretaceous - Tertiary boundary.

Three separate lithological units were sampled and analysed: the Maastrichtian Chalk, the Fish Clay and the Danian Chalk:

Maastrichtian Chalk unit ("White Chalk" and "Bryozoan Chalk"):

Two samples (SK1 & SK3) yielded moderate to good recovery of microfossils. The assemblages were dominated by planktonic foraminifera (c.85%), mainly *Heterohelix* spp., *Globigerinelloides praerihillensis* and, to a lesser extent *Hedbergella holmdelensis*.

The occurrences of these taxa, together with *Reussella szajnochae szajnochae*, *Cibicides beaumontianus*, *Praebulimina laevis*, *Bolivinoides decoratus* and *Bolivina incrassata*, all indicate a general Maastrichtian age. Furthermore, the apparent absence of certain key index taxa (e.g. *Abathomphalus mayaroensis*, *Pseudotextularia elegans*, *Racemiguembelina fructicosa* etc.) suggests that the latest part of the Maastrichtian may be missing in this section. However, this apparent absence may have been influenced by the prevailing palaeoenvironment (i.e. shallow waters - see below).

The high proportion of planktonic taxa indicates good open marine conditions with a well oxygenated water column. The apparent lack of keeled taxa (e.g. *A.mayaroensis*) suggests that palaeodepths were, however, relatively shallow - perhaps no more than 50 metres or so.

Fish Clay unit:

The single sample from the Fish Clay unit (SK5) yielded an extremely impoverished assemblage of microfossils comprising *Heterohelix* spp., *Bolivinoides decoratus, Gavelinella voltziana* "group" and *Bolivinoides paleocenicus*. Taken at face value, this assemblage supports Hultberg's conclusion (1985) based on palynological evidence that the Fish Clay unit at Stevns Klint should be placed in the uppermost Maastrichtian rather than the lowermost Danian and that the unit (within Denmark at least) is probably diachronous. This has significant implications for the various end-Cretaceous "catastrophe" theories, too numerous to elaborate here.

However, it is also possible that these fossils may have been derived from underlying Maastrichtian sediments via chalk clasts found near the top of the Fish Clay unit (Bed V of Christensen *et al.*, 1973 - see Text Figure 8). Certainly, no Danian foraminiferal taxa were forthcoming, but if the depositional environment for the Fish Clay at Stevns Klint is indeed of low salinity or brackish (as proposed by Hultberg, 1985), this would account for their apparent absence.

Danian Chalk ("Cerithium Limestone" and "Bryozoan Limestone") units:

Samples SK6, SK7 & SK8 (from the Cerithium Limestone) displayed an upwards increase in recovery and diversity although reworked taxa (mainly *Heterohelix* spp., *Stensioeina pommerana* and *Eouvigerina aculeata*) were also common, particularly near the base. This reworking is not surprising given the degree of burrowing by *Thalassinoides* observed in this section.

Evidence for a Tertiary age is provided by the occurrences of *Tappanina selmensis* and *?Cibicides tenellus* in the lowermost sample (SK6), and by the lowest occurrences of typical Danian / Tertiary planktonic taxa (i.e: *Morozovella pseudobulloides* (*sensu stricto* and "cf."), *Chiloguembelina* spp., and *?Globoconusa daubjergensis* (in sample SK7). A relative influx of these typical small Danian planktonics occurs in sample SK8.

The remaining samples from the Bryozoan Limestone (SK9, SK11, SK13, SK16, SK18 & SK19) yielded microfaunal assemblages which differed somewhat from the assemblages from the Cerithium Limestone and yielded moderately rich and diverse assemblages dominated by small planktonic taxa.. *M.pseudobulloides* and *Eoglobigerina* spp. are abundant with *Globoconusa daubjergensis* and *Guembelitria triseriata* also common.

In terms of stratigraphic age for the Danian Chalk unit as a whole, the occurrence of *M.pseudobulloides* in the next to lowest sample (SK7) indicates an age no older than Zone P1 (Blow, 1979). Other taxa recorded (i.e. *M.*cf.*pseudobulloides, G.daubjergensis, Eoglobigerina trivialis, E.*aff.*trivialis, Eoglobigerina eobulloides* "group" and *Eoglobigerina edita* "group") can range below Zone P1 and down to the base of the lowermost Tertiary planktonic foraminiferal zone, Zone Pα. However, taxa *restricted* to that zone (e.g. *Eoglobigerina edita* cf. *praeedita, Eoglobigerina eobulloides* cf. *simplicissima, Eoglobigerina* Types I - IV *sensu* Blow 1979, *Globorotalia* Types I - IV *sensu* Blow 1979, *M.*aff*pseudobulloides, G.*cf.*archaeocompressa* plus other taxa typical of the very basal Danian including *Globigerina fringa* and *G.eugubina*) were not recorded.

The presence of *Eoglobigerina eobulloides simplicissima* in the uppermost sample examined (SK19) would, if *in situ*, place an upper age limit of Zone P1 on the Danian Chalk unit exposed at Stevns Klint. The *Eoglobigerina edita* "group" ranges no higher than the mid part of Zone P2 (i.e. the top of the Danian *sensu stricto*) with *G.daubjergensis* and *M.pseudobulloides* ranging to the top of Zone P2 (i.e. into the lower part of the Thanetian).

In conclusion, the age of this Danian Chalk unit exposed at Stevns Klint is Danian, P1 (?possibly lower P2 Zone) Zone with no evidence for an earliest Danian age. This indicates a hiatus at the Cretaceous - Tertiary boundary. This hiatus is represented, at least partly, by the junction between the Fish Clay unit (which is itself probably highly condensed) and the overlying Cerithium Limestone.

10.Conclusions

10.1.General Remarks

In a total of 186 samples studied from 9 offshore North Sea boreholes and 5 onshore boreholes/sections, microfaunas comprising 273 individual taxa were recorded. The majority of these were from the Order Foraminiferida with less common Ostracoda, Diatomacea and Radiolaria also recorded.

On the whole, microfaunal recovery was good although in certain areas (e.g. the Palaeocene - Eocene of borehole 21/26-1D) recovery was extremely poor.

In most cases, where samples from post-chalk sections were analysed, calcareous benthonic foraminifera dominated the microfaunal assemblages followed by agglutinated foraminifera which were locally abundant (e.g. in 29/25-1 and 44/2-1). Planktonic foraminifera were the dominant group recorded from chalk sections, both on- and off-shore, with calcareous benthonic taxa common, though subordinate to them. Planktonic diatoms were recorded from most of the more northerly offshore boreholes (very common in 29/25-1) but were generally very rare to absent elsewhere in the study area. Ostracoda and Radiolaria were sporadically recorded throughout the study area.

Data distribution charts and tables are included in the Appendices of this thesis.

10.2.Biostratigraphy

Biostratigraphic subdivision of the Latest Cretaceous (Maastrichtian) - Early/Middle Eocene interval of the southern Central and Southern North Sea wells studied using the published biozonation scheme of King, 1989, and the bioevents of Mudge & Copestake, 1992, is possible. However, the detail to which this can be achieved depends on many factors both geologically and contemporary (see previous Chapter for discussion on the biostratigraphic subdivision of individual wells / sections).

Contemporary factors include the quantity, quality and frequency of available samples. Most, though certainly not all, of the samples were of sufficient quantity - yielding relatively rich microfossil assemblages. The quality of the samples is, however, debatable as the majority of them are taken from ditch cuttings with their attendant disadvantages (see Chapter 4). Also, in most cases, the sample interval was approximately 30 feet (with a range of between 10 - 50 feet in some cases). This is not sufficient with which to build up a detailed biostratigraphy, and many of the key bioevents occur over relatively short intervals

of both space and time. An example of this is the prolific development of diatoms in the later Palaeocene which can allow a very fine subdivision of that particular interval within the succession. A summary of the top depths of the various King biozones recorded in the offshore boreholes is given in Text Figure 18.

Contemporary economic factors also play their part. Not surprisingly, most of the scientific interest applied to Palaeocene microfossils is centred on offshore hydrocarbon plays where the principal hydrocarbon reservoir is of the same or similar age. In these areas, sample spacing is usually much more frequent, with core and sidewall cores often being taken in addition to the ditch cuttings. The majority of wells studied here are drilled in areas where the primary economic target lies well below the Tertiary. The post-Chalk clastics in these areas are, in effect, just an obstacle to be penetrated as quickly as possible with relatively little interest in their biostratigraphical relationships.

Notwithstanding the caveats mentioned above, geological factors also influence the application of microfossils recorded here to a biostratigraphic framework. The established biozonations of this stratigraphic interval as applied to the North Sea offshore (e.g. King, 1989; Mudge & Copestake, 1992 etc.) were initially erected in areas which were palaeoenvironmentally different to the present area under study. Palaeoenvironments of the Palaeocene of the study area (see below) were generally shallower and more subject to the rise and fall of sea-level and deltaic influences than those of the "main" part of the Central and Northern North Sea. Surface and bottom water characteristics were also subtly different and parts of the area were more removed from the active Hebridean tectonic centre of North Atlantic opening, which fundamentally influenced the microfaunal and floral distribution patterns in the North Sea Basin at the time.

Nevertheless, certain biostratigraphic "events" were recorded fairly consistently throughout the area of study and some correlate quite well with similar events throughout the entire North Sea Basin. Text Figure 19 shows the list of "bioevents" known to be present throughout the latest Cretaceous to Early/Middle Eocene and the degree to which this event has been recorded (e.g. good, probable, possible or absent). The following list of biostratigraphic events are recorded in this study and are thought, therefore, to have useful potential for correlation *within the general Southern North Sea area* (i.e. events may be more or less consistently and/or reliably recorded elsewhere). Note that events are dominated by first downhole occurrences ("tops") to attempt to minimise the effects of caving.

Event FDO=First Downhole Occurrence LDO=Last Downhole Occurrence T.R.=Total Range	**Age**	**Degree of Uncertainty**[8] (1-5=highest-lowest)
T.R. *S.navarroana*	Early Eocene	1
consistent *Acarinina* spp.	Early Eocene	3
F.D.O. *G.chascanona*	Early Eocene	3
T.R. *V.decorata* (*sensu stricto*. and aff.)	Early Eocene	4
F.D.O. *S.linaperta* grp. (consistent)	intra-E. Eocene	1-2
L.D.O. *B.aksuatica*	intra-E. Eocene	4
T.R. *S.*aff.*spectabilis*	intra-E. Eocene	4
F.D.O. *B.trigonalis*	intra-E. Eocene	4-5
F.D.O. *G.hiltermanni*	intra-E. Eocene	4-5
Influx *S.linaperta* grp.	lower E. Eocene	2
T.R. *T.brevispira*	lower E. Eocene	2-3
L.D.O. *Bulimina* sp.A *sensu* King	lower E. Eocene	2-3
L.D.O. *R.amplectens s.s.*	lower E. Eocene	2-3
L.D.O. *A.capitatus*	lower E. Eocene	3
L.D.O. *Cancris* sp.A *sensu* King	lower E. Eocene	4-5
F.D.O. *Coscinodiscus* sp.1	basal E. Eocene	1
T.R. *Coscinodiscus* sp.2	basal E. Eocene	1-2
F.D.O. *Triceratium* spp.	basal E. Eocene	2-3
F.D.O. *Coscinodiscus* sp.20/26 *sensu* G.S.S.	basal E. Eocene	2
F.D.O. *Coscinodiscus* sp.8 *sensu* G.S.S.	basal E. Eocene	3
F.D.O. reworked microfaunas	top Late Palaeocene	5
T.R. *B.midwayensis*	Late Palaeocene	3
T.R. *A.obtusa*	Late Palaeocene	3-4
F.D.O. *S.spectabilis s.s.*	intra-L. Palaeocene	3
F.D.O. abund. & diverse agglutinants	intra-L. Palaeocene	3
F.D.O. cibicidiid-dominated assemblages	intra-L. Palaeocene	3
F.D.O. *K.conversa*	intra-L. Palaeocene	4-5
F.D.O. *S.thanetana*	intra-L. Palaeocene	4-5
F.D.O. *C.dayi*	intra-L. Palaeocene	4-5
F.D.O. and/or Influx *C.lenticularis*	lower L. Palaeocene	3
F.D.O. *Eoglobigerina* spp.	lower L. Palaeocene	4-5
F.D.O. *M.pseudobulloides*	lower L. Palaeocene	4-5
F.D.O. *P.compressa*	lower L. Palaeocene	4-5

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[8] Dependent on reliability of event and/or it's frequency recorded

F.D.O. *M.uncinata*	lower L. Palaeocene	4-5
F.D.O. *M.praecursoria*	lower L. Palaeocene	4-5

------------------- basal Late Palaeocene - upper Early Palaeocene interval ------------------
normally missing in Southern North Sea area

F.D.O. abundant planktonic taxa (chalk-preserved)	intra-E. Palaeocene	1-2
F.D.O. *selmensis*	intra-E. Palaeocene	4
T.R. *G.eugubina / fringa* grp.	basal E. Palaeocene	5

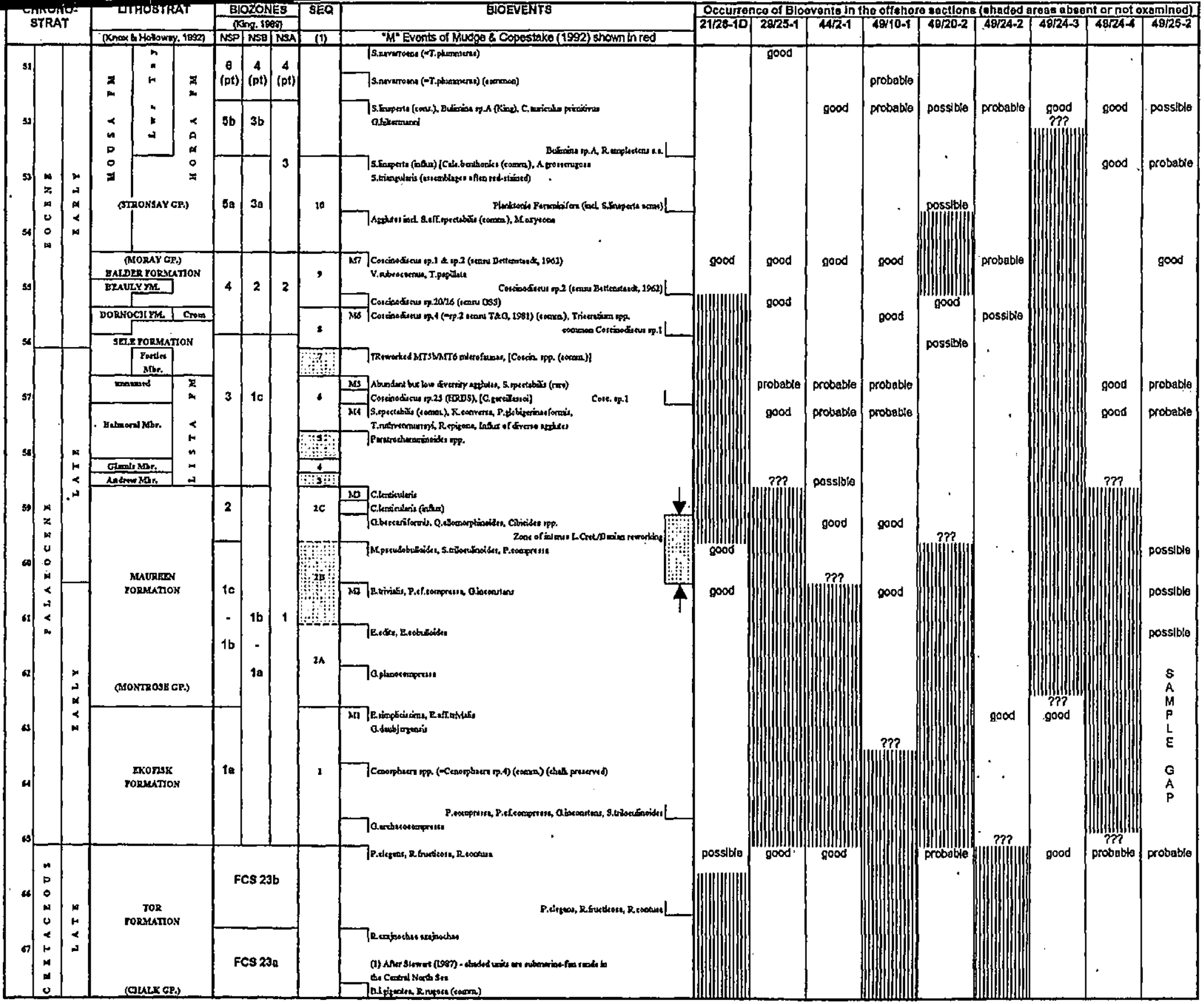
---------------- basal Early Palaeocene - ?upper Late Maastrichtian interval -----------------
normally missing in Southern North Sea area

T.R. *P.elegans*	Late Maastrichtian	2
T.R. *R.fructicosa*	Late Maastrichtian	4
F.D.O. *G.praerihillensis*	Maastrichtian	1
F.D.O. *Rugoglobigerina* spp.	Maastrichtian	3
F.D.O. *P.laevis*	Maastrichtian	1
F.D.O. *G.nitidus*	Maastrichtian	2
F.D.O. *G.pertusa*	Maastrichtian	2-3
F.D.O. *O.navarroana*	Maastrichtian	2-3
F.D.O. *B.draco*	Maastrichtian	3
F.D.O. *C.beaumontianus*	Maastrichtian	4
F.D.O. *B.incrassata*	intra-Maastrichtian	3
F.D.O. *E.aculeata*	Early Maastrichtian	4
F.D.O. *B.miliaris*	Early Maastrichtian	4
F.D.O. *A.cretacea*	Early Maastrichtian	4
F.D.O. *B.laevigatus*	Late Campanian	5

Although not attempted here for the reasons outlined above and below, a separate microbiozonation scheme specific to the Southern North Sea area (i.e. distinct from King, 1989 and Mudge & Copestake, 1992) could be justified given access to more sample material. This scheme would place more emphasis on the calcareous benthonic foraminifera.

Text Figure 18 Depths of biozones recorded in the study wells

CHRONO– STRAT.	BIOSTRAT. ZONATION (after King, 1989)			STUDY WELLS								
	NSA	NSP	NSB	21/26-1	29/25-1	44/2-1	49/10-1	49/20-2	49/24-2	49/24-3	49/24-4	49/25-2
Middle Eocene (or younger)	NO ZONES ASSIGNED ▨ = missing										?1460'	2030' ▨ ?
Earliest M.Eocene - Latest E.Eocene	NSA 4	NSP 6	NSB 4		5800'	?2730'			?1860'		1460'	▨
intra-Early Eocene	NSA 3	NSP 5b	NSB 3b	2950'		2760'	2820'	2490'	1900'	1700'	?1550'	2050'
		NSP 5a	NSB 3a			2790'						2200'
Earliest Eocene - Latest Palaeocene	NSA 2	NSP 4	NSB 2	3270'	5856'	2820'	2860'	▨ 2610'	1955'	▨		2410'
intra-Late Palaeocene	NSA 1	NSP 3	NSB 1c	3300'	5944'	▨	?2900'	2640'	▨ ?	▨	1700'	2440'
		NSP 2	NSB 1b			2850'			▨ ?	▨	▨	
		NSP 1c							?1985'	▨	▨	2530'
Early Palaeocene		NSP 1b	NSB 1a	3495'	▨	▨	3003'	▨	2219'	1760'	▨	▨ ?
		NSP 1a			▨	▨		▨			▨	▨ ?
Late Cretaceous	NO ZONES ASSIGNED			3610'	6132'	2990'	?3037'	2790'		1780'	1790'	?2670'



Text Figure 19 Key bioevents recorded in the sections studied

10.3. Palaeoenvironment

Conditions during the latest part of the Cretaceous (Maastrichtian) in the study area were rather "benign" with respect to the foraminifera in that seas were comparatively deep, well oxygenated, warm and covered much of the present-day land surface. Tectonic activity within the study area and around the margins was, to all intents and purposes, extremely limited and had very little, or no effect on the geological processes occurring at the time. Sediment supply from submerged sources (and the few small emergent islands) was sparse and the primary source of sedimentation was the calcareous hard parts of marine phytoplankton (nannofossils) together with calcareous matter from other biological sources. Ambient temperatures at these latitudes were thought to be comparatively warmer than at present and probably somewhat drier as well. The marine environment supported thriving micro and macro planktonic and benthonic faunal and floral communities.

These overall conditions resulted in the deposition of the Chalk Group (offshore) and the well-known chalk sequences of southern England and other countries surrounding the North Sea Basin. Similar carbonate sequences have been recorded worldwide, testifying to the uniform, almost global conditions prevailing during those times.

Towards the end of the Maastrichtian stage, the relatively benign palaeoenvironmental setting deteriorated progressively with evidence from many sources indicating the evolutionary decline of many representatives of the plant and animal kingdom, culminating in the well-known mass extinction at the end of the Cretaceous. A multitude of hypotheses have been proposed to account for this event ranging from evolutionary "decay" to cometary impact and the so-called *Nemesis* rogue-star. A full discussion of these theories is beyond the scope of this work, although results indicate that the extinction event was not completely "successful" and that a few taxa recorded in this study survived to cross the boundary into the Tertiary.

The boundary in Northwest Europe is often marked by an apparent break in deposition although in Denmark, the boundary is thought to be as complete as possible and is represented (albeit perhaps somewhat diachronously) by the so-called Fish Clay layer of thin marls.

The Cretaceous - Tertiary extinction event coincided with a basinwide regression although this was short-lived and open marine conditions soon returned to most of the region although the sea never re-achieved its earlier size in terms of area or depth. Tectonically, conditions were still relatively quiescent and carbonate deposition resumed with the deposition of the Danian limestones of Denmark and the Ekofisk Formation of the North Sea offshore.

At about this time, the early manifestations of tectonic activity to the northwest of the study area (i.e. the incipient opening of the area between NW Europe and Greenland to form the North Atlantic Ocean) began to exert an influence on geological processes occurring in the North Sea Basin.

Limestone deposition (of the Ekofisk Formation) continued into the early part of the Palaeocene although subsequent uplift has eroded much of this from all but the central parts of the basin. Deposition of these lithologies took place under comparatively shallow marine conditions though at depths greater than normal wave-base influence as evidenced by the sedimentary features displayed in the onshore Danish sections.

The junction between the "true" limestones of the Ekofisk Formation and that of the overlying marly Maureen Formation is very seldom continuous and conformable. It is therefore difficult to interpret precisely the prevailing environments of deposition during this important phase of North Sea history although the primary cause of the fundamental change in depositional regimes is thought to be the incipient opening of the North Atlantic ocean and its subsequent effects on sea levels.

Carbonate deposition was not abruptly "switched off' towards the end of the Early Palaeocene (Danian), but rather it seems that clastic deposition began to gradually increase - steadily "diluting" the effects of the previous carbonate regime. This is not readily observed at onshore localities but is evidenced by the occurrence of marly lithologies (the Maureen Formation and its equivalents) observed in many offshore boreholes.

Progressively however, the sediments from the North Sea Basin became wholly clastic-dominated during the early part of the Late Palaeocene (Thanetian). The majority of sediments of this age from the study area were deposited under shallow shelf seas, somewhat distal from a deltaic complex building out from the west or southwest.

Microfaunal assemblages from onshore U.K. localities indicate distal delta-front conditions (Pegwell Bay) with progressive silting up of the basin resulting in the more proximal delta front silts of Reculver and, eventually, the marginal and non marine sediments of the Woolwich and Reading Beds. Sediments thought to be broadly contemporary with the Pegwell Marls from onshore Denmark (the Kerteminde Marl) appear to have been deposited under similar conditions. Whilst water depths were comparatively shallow (see below) the bottom waters appear to have been normally (or nearly so) oxygenated.

In some parts of the study area particularly towards the north, i.e. into the southern reaches of the Central Graben, evidence for increased water depth (due to basin subsidence) is recorded. Due to poor water circulation at depth, bottom waters in these parts of the basin

were poorly or non-oxygenated and this had a significant influence on the resulting fossil microfaunal and floral assemblages, resulting in the widespread occurrence of the so-called "*Rhabdammina* biofacies". However, the majority of boreholes in the southern part of the study area continue to indicate at least reasonably well oxygenated bottom waters. Microfaunal distribution patterns from this part of the study area were more likely influenced by a relatively mobile shoreline, moving in response to minor sea level fluctuations over a shallow shelf gradient.

Meanwhile to the northwest of the region as a whole, opening of the North Atlantic ocean continued apace. The resulting associated volcanic activity culminated in the deposition of ash-rich sediments across much of Northwest Europe, especially during latest Palaeocene and earliest Eocene times. The often abundant diatomaceous microflora recorded in association with these sediments are not thought to be a direct result of surface water enrichment by volcanic silica, rather as the result of strong nutrient input into the Basin via the northward excursion of low-latitude water masses.

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Appendices

Palaeontological Distribution Charts
Plates

Appendix 1: Palaeontological Distribution Charts

The first part of this appendix contains a list of the individual taxa (grouped in alphabetical order within broad group-types) recorded in the work and a simple histogram reflecting their total abundances in each of the boreholes/localities studied.

The second part of Appendix 1 consists of scaled vertical (i.e. depth stratigraphic) distribution charts for the individual offshore and onshore boreholes which are plotted using the "StrataBugs" database system. Data is presented in histogram format based on numerical counts of specimens in each sample. 30mm of histogram length represents a count of 100 specimens. Interpreted chronostratigraphy and biozonation is included on the charts as well as significant biostratigraphical events and bar-charts showing relative percentages of different microfaunal groups (e.g. diatoms, agglutinated taxa, planktonic taxa etc.) for each sample. Bar charts are not displayed for the Wormingford Mere onshore borehole as the vast majority of specimens are interpreted as reworked.

For onshore sections, the "StrataBugs" database cannot be used as sample spacing is normally too small (i.e. often less than 1 metre between samples) for the database to cope with. Species distribution is therefore presented on a series of charts created using an "Excel" spreadsheet. Symbology is slightly different from those used on "StrataBugs" charts:

Sample	Abundance	Numeric
○	rare/present	1 - 4
⭘	common	5 - 9
●	very common	10 - 25
■	abundant	25 plus

DISTRIBUTION OF TAXA THROUGHOUT THE STUDY AREA

FOSSIL TYPES:		
	AGG	Agglutinated Foraminifera
	CAL	Calcareous Benthonic Foraminifera
	PLA	Planktonic Foraminifera
	SIL	Siliceous Microfossils (Radiolaria, Diatoms etc.)
	OST	Ostracoda
	OTH	Other fossil types

OCCURRENCES:			
	?	questionable	present but identification is uncertain
	■	rare	i.e. c.<10 specimens throughout the whole section
	■■	moderately common	i.e. c.10-50 specimens throughout the whole section
	■■■	common	i.e. c.50-100 specimens throughout the whole section
	■■■■	very common	i.e. c.100-200 specimens throughout the whole section
	■■■■■	abundant	i.e. c.>200 specimens throughout the whole section

TAXON			U.K. OFFSHORE									U.K. ONSHORE			DENMARK ONSHORE	
Genus	species	TYPE	21/26-1D	29/25-1	44/2-1	49/10-1	49/20-2	49/24-2	49/24-3	49/24-4	49/25-2	WOR.MERE	PEG.BAY	RECULVER	LUND.CLIFF	STEV.KLT
Ammobaculites	*spp.*	AGG		■												
Ammodiscus	*cretaceus*	AGG	■	■■■	■■	■■■			■	■	■■					
Ammodiscus	*peruvianus*	AGG		■■	■■	■					■					
Bathysiphon	*discreta*	AGG		■■	■	■■		■	■		■	■				
Clavulina	*anglica*	AGG									■					
Cribrostomoides	*scitulus*	AGG			■	■										
Cribrostomoides	*spp.*	AGG		■		■										
Gaudryina	*hiltermanni*	AGG							■	■	■					
Glomospira	*charoides*	AGG	■	■■	■■■	■■		■	■	■	■■					■
Glomospira	*gordialis*	AGG	■	■	■■	■					■					
Glomospirella	*woodi*	AGG	■	■	■■	?			■	■	■		■■			
Haplophragmoides	*/ Cyclamnina spp.*	AGG	■	■■■	■■	■■■										
Haplophragmoides	*/ Recurvoides spp.*	AGG		■		■										
Haplophragmoides	*walteri*	AGG		■■												
Karrerlella	*conversa*	AGG		■■	■■	■				■						
Marssonella	*spp.*	AGG		■												
Matanzia	*varians*	AGG			■										■	
Praecystammina	*globigerinaeformis*	AGG			■■	■			?							
Recurvoides	*walteri gr.*	AGG			■■	■								■		
Reophax	*pilulifer*	AGG		■					?							
Reticulophragmium	*amplectens*	AGG		■■	■	■		?								
Reticulophragmium	*amplectens (aff.)(= R.sp.A King)*	AGG		■	■											
Reticulophragmium	*placenta*	AGG		■	■■						■					
Reticulophragmium	*spp.*	AGG		■	■											
Rhizammina	*indivisa*	AGG		■■	■	■■■										
Rzehakina	*epigona*	AGG									■					
Rzehakina	*sp.1 (Gradstein & Berggren)*	AGG									■					
Silicosigmoilina	*sp.King*	AGG		?						■						
Spiroplectammina	*adamsi*	AGG						■	■	■	?					
Spiroplectammina	*carinata*	AGG				■					?					
Spiroplectammina	*navarroana (T.plummerae)*	AGG		■	?	■■				■						
Spiroplectammina	*spectabilis*	AGG		■	■						?					
Spiroplectammina	*spectabilis (aff.) (sensu King)*	AGG			■											
Spiroplectammina	*thanetana*	AGG									■		■■■	■■■■		
Thurammina	*spp.*	AGG			?	■■			■							
Trochammina	*deformis*	AGG		■■	■											
Trochammina	*globigeriniformis*	AGG		■■												
Trochammina	*spp.*	AGG		■		■■										
Trochammina?	*volupta*	AGG											?			
Alabamina	*obtusa*	CAL						■	■	■	■		■		■	
Alabamina	*solnasensis*	CAL													■	
Allomorphina	*trigona*	CAL						?	■							
Angulogavelinella	*bettenstaedti*	CAL					?									
Angulogerina	*spp.*	CAL				?										
Anomalina	*spp.*	CAL	■	■			■	■								
Anomalinoides	*acuta*	CAL					■									
Anomalinoides	*capitatus*	CAL			■	■				■	■					
Anomalinoides	*nobilis*	CAL			■						■		■	■		

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	OTH	Other fossil types

OCCURRENCES:			
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	■	rare	i.e. c.<10 specimens throughout the whole section
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	■■■	common	i.e. c.50-100 specimens throughout the whole section
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			U.K. OFFSHORE									U.K. ONSHORE			DENMARK ONSHORE	
TAXON																
Genus	species	TYPE	21/26-1D	29/25-1	44/2-1	49/10-1	49/20-2	49/24-2	49/24-3	49/24-4	49/25-2	WOR.MERE	PEG.BAY	RECULVER	LUND.CLIFF	STEV.KLT
Astacolus	*sp.nov.*	CAL									■		■■■		■	
Asterigerina	*aberystwythi*	CAL				?										
Bolivina	*incrassata (inc. B.i.gigantea)*	CAL			■■						■■			■		■
Bolivina	*spp.*	CAL									■					
Bolivinoides	*decoratus*	CAL														■
Bolivinoides	*draco*	CAL		■	■				■		■					
Bolivinoides	*laevigatus*	CAL							■		?	■		■		
Bolivinoides	*miliaris*	CAL			■											
Bolivinoides	*palaeocenicus*	CAL			?											■
Brizalina	*spp.*	CAL			■	■										
Buccella	*propingua*	CAL									?					
Bulimina	*aksuatica*	CAL			■	■		■	■	■	■■					
Bulimina	*midwayensis*	CAL			■			■			■				■	
Bulimina	*sp.A.King*	CAL				■■			■	■	■					
Bulimina	*spp.*	CAL	■			■					■					
Bulimina	*trigonalis*	CAL	?		■	■	■	■	■		■		■■■■■	■	■■	
Cancris	*sp.A (King)*	CAL									?					
Ceratobulimina	*contraria*	CAL						■			■					
Cibicides	*beaumontianus.*	CAL				?			?		■					■
Cibicides	*cantii*	CAL											■■	■■■		
Cibicides	*cassivelauni*	CAL									?		■■	■■■		
Cibicides	*cunobelini*	CAL									?		■■	■■■■■		
Cibicides	*lobatulus*	CAL									■		■■			
Cibicides	*mariae*	CAL											■■	■■■■■		
Cibicides	*pseudoungerianus*	CAL				■		■	■							
Cibicides	*simplex (cf.)*	CAL								■	■					
Cibicides	*spp.*	CAL	■	■■	■■	■■■	■	■■	■■	■	■■■■				■	■■
Cibicides	*tenellus*	CAL					?	■	■	■	■					?
Cibicides	*ungerianus (cf.)*	CAL			■					■	■					
Cibicides	*westi*	CAL									■					
Cibicidoides	*alleni*	CAL	■								■		■	■	■■	
Cibicidoides	*dayi*	CAL									■					
Cibicidoides	*dutemplei gr.*	CAL	■		■■	■■	■	■	■	■						
Cibicidoides	*eocaenus*	CAL									■					
Cibicidoides	*pachyderma*	CAL		?	?	?		■	■		?					
Cibicidoides	*pygmeus*	CAL								■	■					
Cibicidoides	*succedens*	CAL				■	?		?	■■			■■	■■	■■	
Cibicidoides	*susanaensis*	CAL									■					
Cibicidoides	*truncanus*	CAL			■	■		■	?	■	■					
Conorotalites	*aptiensis*	CAL										?				
Cytharina	*plumoides*	CAL														
Dentalina	*colei*	CAL									■				■■	
Dentalina	*frankei*	CAL														
Dentalina	*glaessneri*	CAL											■		■	
Dentalina	*plummerae*	CAL													■	
Dentalina	*spp.*	CAL			■	■	■	■	■		■	■	■			
Elphidium	*spp.*	CAL						?								
Bouvigerina	*aculeata*	CAL							■	■		■		■		■■

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	OTH	Other fossil types

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Genus	species	TYPE	21/26-1D	29/25-1	44/2-1	49/10-1	49/20-2	49/24-2	49/24-3	49/24-4	49/25-2	WOR.MERE	PEG.BAY	RECULVER	LUND.CLIFF	STEV.KLT
Bouvigerina	*spp.*	CAL			■											
Epistominella	*vitrea*	CAL												■■■		
Eponides	*spp.*	CAL	■		■	■	■	■	■							
Frondicularia	*tenuissima*	CAL													■	
Gavelinella	*baltica*	CAL										?				
Gavelinella	*beccariiformis*	CAL	■		■■							■			■■■	
Gavelinella	*bambix*	CAL					■									
Gavelinella	*danica*	CAL								■	■					
Gavelinella	*lorneiana*	CAL										■				
Gavelinella	*pertusa*	CAL			■		■		?		■					
Gavelinella	*spp.*	CAL	■	■	■■■	■	■	?	?		■■■	■■				■■■
Gavelinella	*voltziana gr.*	CAL			■■■		■		■	■	■■■					■■■
Glandulina	*laevigata*	CAL									■			?	■■	
Globorotalites	*micheliniana*	CAL										■				
Globorotalites	*spp.*	CAL						?								
Globulina	*ampulla*	CAL									■		■	■■		
Guttulina	*problema*	CAL									■		■	■■	■	
Gyroidina	*soldanii girardana*	CAL		■		■		■	■	■	■					
Gyroidinoides	*angustiumbilicatus*	CAL									■				■	
Gyroidinoides	*danvillensis var. gyroidinoides*	CAL									■		■	■		
Gyroidinoides	*nitidus*	CAL		■	■						■■■	■				
Gyroidinoides	*octacamerata*	CAL														
Gyroidinoides	*spp.*	CAL			■	■	■	■	■	■						
Hanesina	*orbiculare*	CAL							■							
Heterolepa	*pegwellensis*	CAL											■	■		
Hoeglundina	*elegans*	CAL								?						
Lagena	*geometrica*	CAL													■	
Lagena	*inornata*	CAL											?			■
Lagena	*spp.*	CAL	■		■	?							■			
Lamarckina	*paleocenica*	CAL													■	
Lenticulina	*klagshamnensis*	CAL													■	
Lenticulina	*multiformis*	CAL				?		?	■		■					
Lenticulina	*schreiteri*	CAL										■				
Lenticulina	*spp.*	CAL	■		■	■■		■	■■	■■	■■					■
Lenticulina	*turbinatus*	CAL													■■	
Lingulogavelinella?	*gyroidinaeformis*	CAL														
Loxostomum	*eleyi*	CAL										■				
Marginulina	*gracilis*	CAL										■				?
Marginulinopsis	*paleocenicus*	CAL														
Melonis	*pompilioides*	CAL	■		■■	■		■	■		■					
Neoeponides	*karsteni*	CAL									■					
Nodosaria	*konincki*	CAL				■										
Nodosaria	*latejugata*	CAL								■	■			■	?	
Nodosaria	*minor*	CAL														
Nodosaria	*spinescens*	CAL									■■					
Nodosaria	*spp.*	CAL			■■	■■	■	■	■	■		■				
Nonion	*applinae*	CAL											■	■		
Nonion	*laeve*	CAL									?		■	■		

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	■■■■	very common	i.e. c.100-200 specimens throughout the whole section
	■■■■■	abundant	i.e. c.>200 specimens throughout the whole section

TAXON			U.K. OFFSHORE									U.K. ONSHORE			DENMARK ONSHORE	
Genus	species	TYPE	21/26-1D	29/25-1	44/2-1	49/10-1	49/20-2	49/24-2	49/24-3	49/24-4	49/25-2	WOR.MERE	PEG.BAY	RECULVER	LUND.CLIFF	STEV.KLT
Nonionella	*cretacea*	CAL												■	■	
Osangularia	*navarroana*	CAL		■							■					■
Osangularia	*spp.*	CAL		■			?									
Pararotalia	*spp.*	CAL									?			?		
Patellina	*spp.*	CAL					?									
Planularia	*baierana*	CAL										■				
Planulina	*costata*	CAL				■			?							
Planulina	*spp.*	CAL			?											
Polymorphinidae	*undifferentiated*	CAL		■		■			■							
Praebulimina	*laevis*	CAL		■	■				■		■■■	■				■■
Praebulimina	*spp.*	CAL		■		?				■		■				
Praeglobobulimina	*ovata*	CAL												?		
Proteiphidium	*hofkeri*	CAL												■■		
Pseudonodosaria	*spp.*	CAL									■					
Pullenia	*quaternaria*	CAL									■					■
Pullenia	*quinqueloba*	CAL	■		■■	■		■■	■■	■■	■■		■	■■	■■	■
Pulsiphonina	*prima*	CAL								■	■■					
Quadrimorphina	*allomorphinoides*	CAL				■										■
Quinqueloculina	*reicheli*	CAL									■					
Quinqueloculina	*spp.*	CAL				■					■					
Reusella	*spp.*	CAL	■													
Reusella	*szajnochae szajnochae*	CAL														■
Rosalina	*binkhorsti*	CAL	■													
Rosalina	*squamiformis*	CAL														■
Sagrina	*selseyensis*	CAL								■						
Saracenaria	*hartingi*	CAL													■	
Saracenaria	*spp.*	CAL		■	■	■										
Sigmomorphina	*soluta*	CAL												■		
Siphonina	*reticulata*	CAL	■			■	■	■■■	■■	■	■■					
Sphaeroidina	*bulloides*	CAL						■		■		■				
Stensioeina	*pommerana*	CAL										■				■
Stilostomella	*pseudoscripta*	CAL			■											
Stilostomella	*spp.*	CAL														■
Stilostomella	*subspinosa*	CAL									■					
Tappanina	*selmensis*	CAL				?		■				■				■■
Trifarina	*spp.*	CAL				■										
Tritaxia	*spp.*	CAL										■				
Turrilina	*brevispira*	CAL	■		?	■		■	■	■	■					
Uvigerina	*batjesi*	CAL								■	■					
Uvigerina	*eocaena*	CAL				■					■					
Uvigerina	*farinosa*	CAL									■					
Uvigerina	*germanica*	CAL				■										
Uvigerina	*spp.*	CAL						■	■							
Uvigerina	*tenuipustulata*	CAL				■										
Vaginulinopsis	*decorata*	CAL				■		■	■	■	■					
Vaginulinopsis	*decorata (aff.) (=V.sp.B King)*	CAL			?			■		■						
Vaginulinopsis	*decorata subsp.A (King)*	CAL								■	■					
Bairdia	*spp.*	OST							■							

DISTRIBUTION OF TAXA THROUGHOUT THE STUDY AREA

FOSSIL TYPES:		
	AGG	Agglutinated Foraminifera
	CAL	Calcareous Benthonic Foraminifera
	PLA	Planktonic Foraminifera
	SIL	Siliceous Microfossils (Radiolaria, Diatoms etc.)
	OST	Ostracoda
	OTH	Other fossil types

OCCURRENCES:			
	?	questionable	present but identification is uncertain
	■	rare	i.e. c.<10 specimens throughout the whole section
	■■	moderately common	i.e. c.10-50 specimens throughout the whole section
	■■■	common	i.e. c.50-100 specimens throughout the whole section
	■■■■	very common	i.e. c.100-200 specimens throughout the whole section
	■■■■■	abundant	i.e. c.>200 specimens throughout the whole section

			U.K. OFFSHORE									U.K. ONSHORE			DENMARK ONSHORE	
TAXON																
Genus	species	TYPE	21/26-1D	29/25-1	44/2-1	49/10-1	49/20-2	49/24-2	49/24-3	49/24-4	49/25-2	WOR.MERE	PEG.BAY	RECULVER	LUND.CLIFF	STEV.KLT
Cyamocytheridea	*magna*	OST												?		
Cytheropteron	*spp.*	OST		■				?								
Hazelina	*thanetensis*	OST											■	■■		
Ostracoda	*undifferentiated.*	OST			■				■	■						
Brachiopoda	*undifferentiated*	OTH							■							
Fish teeth	*undifferentiated*	OTH						■								
Spheres / Discs	*undifferentiated*	OTH														
Abathomphalus	*mayaroensis*	PLA														
Acarinina	*bullbrooki "group"*	PLA				■					■					
Acarinina	*mckannai "group"*	PLA									■					
Acarinina	*soldadoensis "group"*	PLA				■		■		■	?	?				
Acarinina	*wilcoxensis "group"*	PLA						■■	■	■■■	■■					
Archaeoglobigerina	*cretacea*	PLA										■				
Catapsydrax	*spp.*	PLA				■					■					
Chiloguembelina	*cubensis*	PLA	■■	■	■		■	■	■■		■	■	■			■
Eoglobigerina	*edita s.l.*	PLA	■■	■					■							■■■■
Eoglobigerina	*eobulloides s.l.*	PLA	■■■■■													■■■■■
Eoglobigerina	*spp.*	PLA	■■■■■					■	■■	?	?					
Eoglobigerina	*trivialis (aff.)*	PLA														■
Eoglobigerina	*trivialis s.l.*	PLA				■										■■
Globanomalina	*micra*	PLA	■		■	■■		■■	■	■	■■					
Globanomalina	*wilcoxensis*	PLA	■			■■■	■■	■■■■■	■■■■■	■■■■	■■■■■					
Globigerina	*chascanona*	PLA					■	■■	■■	■■	■■					
Globigerina	*danvillensis*	PLA					■				■					
Globigerina	*augubina / fringa "group"*	PLA							■							
Globigerina	*inaequispira*	PLA	■													
Globigerina	*officinalis*	PLA			?	■			■							
Globigerina	*patagonica*	PLA					■			■						
Globigerina	*spp.*	PLA	■■■■■	■■	■■	■■■■	■■	■■■■	■■		■■■	■			■	■■■■■
Globigerinelloides	*prariehillensis*	PLA	?	■	■■■■■				■	■	■■■	■				■■
Globigerinelloides	*spp.*	PLA										■■			■	
Globoconusa	*daubjergensis*	PLA						■	?	?		?				■■■
Globorotalia	*archaeocompressa*	PLA	■													
Globorotalia	*haunsbergensis*	PLA	?			?										
Globorotalia	*inconstans*	PLA	?													
Globorotalia	*perclara*	PLA											■			
Globorotalia	*planocompressa*	PLA	■			?							?			
Globorotalia	*polycamera*	PLA		■												
Globorotalia	*praescitula s.l.*	PLA				■		■								
Globorotalia	*reissi*	PLA									■■					
Globorotalia	*sp.A ?sp.nov.*	PLA		■■■■■												
Globorotalia	*sp.B ?sp.nov.*	PLA		■■■■■												
Globorotalia	*spp.*	PLA	■	■					■						■	
Globotruncana	*bulloides*	PLA										■				
Globotruncana	*linneiana*	PLA		■												
Globotruncanella	*havanensis*	PLA			■											
Guembelitria	*triseriata*	PLA			■			■	■							■■
Hedbergella	*holmdelensis*	PLA		■■	■■							■■■				■■

DISTRIBUTION OF TAXA THROUGHOUT THE STUDY AREA

FOSSIL TYPES:		
	AGG	Agglutinated Foraminifera
	CAL	Calcareous Benthonic Foraminifera
	PLA	Planktonic Foraminifera
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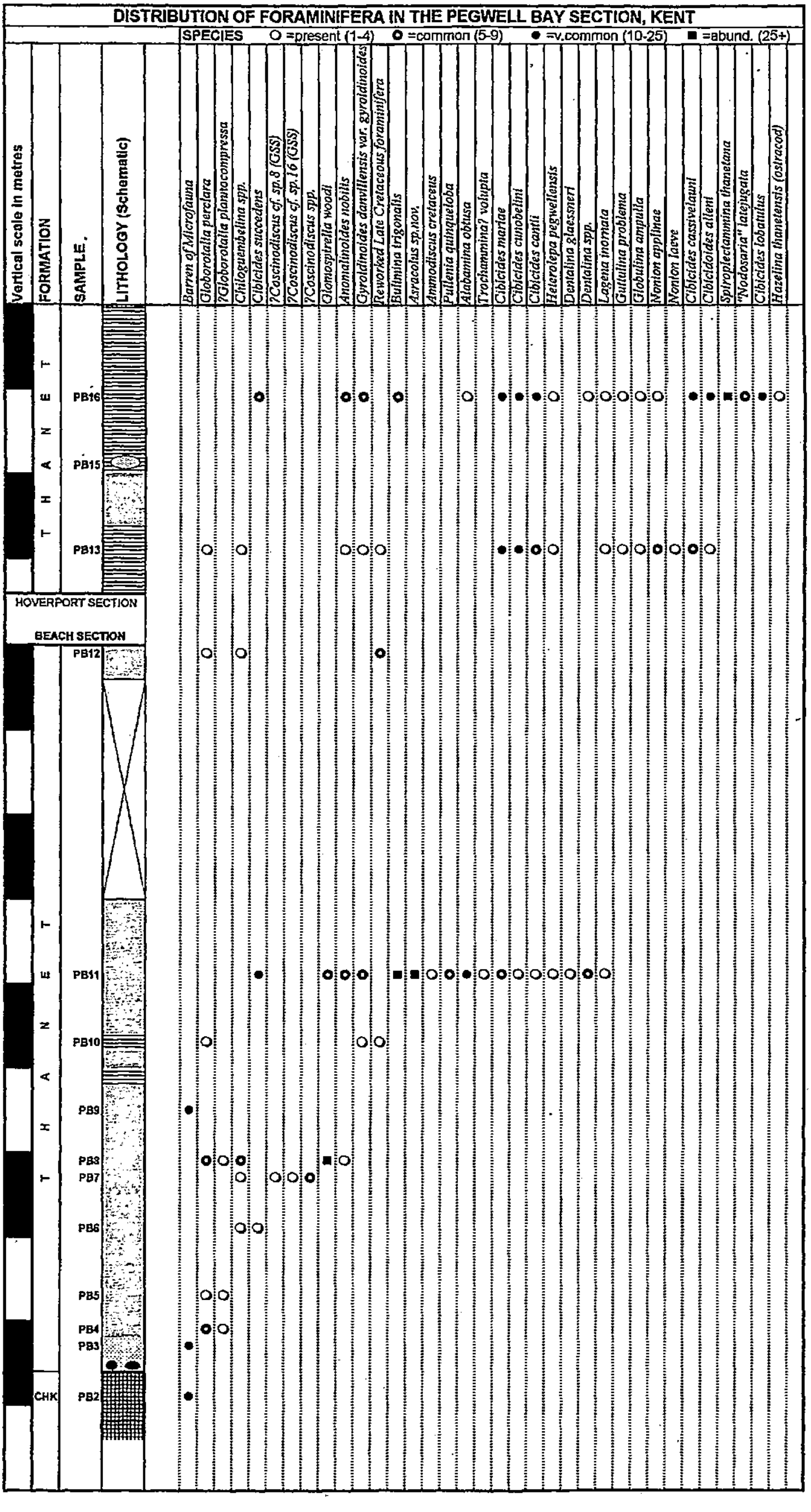
	■■■■■	abundant	i.e. c.>200 specimens throughout the whole section

TAXON			U.K. OFFSHORE									U.K. ONSHORE			DENMARK ONSHORE	
Genus	species	TYPE	21/26-1D	29/25-1	44/2-1	49/10-1	49/20-2	49/24-2	49/24-3	49/24-4	49/25-2	WOR.MERE	PEG.BAY	RECULVER	LUND.CLIFF	STEV.KLT
Heterohelix	*spp.*	PLA		■■	■■■■■				■■■■■	■	■■■■■	■				■■■
Morozovella	*praecursoria*	PLA						?	?		■					
Morozovella	*pseudobulloides*	PLA	■■■■	■			■	■			?	?		?		■■■■■
Morozovella	*pseudobulloides (cf.)*	PLA							■							■■
Morozovella	*uncinata*	PLA	?		?			?								
Planorotalites	*chapmani*	PLA	?	?		■					?			?		
Planorotalites	*compressa*	PLA	■■			■										
Pseudotextularia	*elegans*	PLA	?	■■					■							
Racemiguembelina	*fructicosa*	PLA		■												
Rugoglobigerina	*rugosa*	PLA			■■											
Rugoglobigerina	*spp.*	PLA		?	■■■							■■				?
Subbotina	*frontosa*	PLA									?					
Subbotina	*linaperta "group"*	PLA	■		■■■	■■■	■	■■	■■	■■	■■					
Subbotina	*linaper*-*/eocaena*	PLA									■■					
Subbotina	*triangularis*	PLA	■■		■	■■		■■	■■	■	■			?		
Subbotina	*triloculinoides*	PLA	■■					■			■					■■
Undifferentiated	*hispid planktonics*	PLA			■					■						
Bolboforma	*clodiusi*	SIL						■								
Canosphaera	*lenticularis*	SIL					?	?								
Canosphaera	*spp.*	SIL	■		■■	?										
Coscinodiscus	*sp.01 (Bettenstaedt)*	SIL	?	■■■	■	■■					■					
Coscinodiscus	*sp.02 (Bettenstaedt)*	SIL	?	?	■■	■		■	■							
Coscinodiscus	*sp.08 (GSS)*	SIL											■			
Coscinodiscus	*sp.16 (GSS)*	SIL											■			
Coscinodiscus	*sp.20/26 (GSS)*	SIL		■■			■■									
Coscinodiscus	*spp.*	SIL			■						■			■		
Diatoms	*undifferentiated*	SIL	■	■■■	■	■■		?		?						
Radiolaria	*undifferentiated*	SIL	■													
Triceratium	*cf. abyssorum*	SIL		■■												
Triceratium	*sp.01 (GSS)*	SIL		■■												
Triceratium	*sp.03 (GSS)*	SIL		■												
Triceratium	*spp.*	SIL		■■												



DISTRIBUTION OF FORAMINIFERA IN THE PEGWELL BAY SECTION, KENT

SPECIES ○ =present (1-4) ◉ =common (5-9) ● =v.common (10-25) ■ =abund. (25+)

FORMATION	SAMPLE	*Barren of Microfauna*	*Globorotalia perclara*	*?Globorotalia planocompressa*	*Chiloguembelina spp.*	*Cibicides succedens*	*?Coscinodiscus cf. sp.8 (GSS)*	*?Coscinodiscus cf. sp.16 (GSS)*	*?Coscinodiscus spp.*	*Glomospirella woodi*	*Anomalinoides nobilis*	*Gyroidinoides danvillensis var. gyroidinoides*	*Reworked Late Cretaceous foraminifera*	*Bulimina trigonalis*	*Asracolus sp.nov.*	*Ammodiscus cretaceus*	*Pullenia quinqueloba*	*Alabamina obtusa*	*Trochammina? volupta*	*Cibicides mariae*	*Cibicides cunobelini*	*Cibicides cantii*	*Heterolepa pegwellensis*	*Dentalina glaessneri*	*Dentalina spp.*	*Lagena inornata*	*Guttulina problema*	*Globulina ampulla*	*Nonion applinae*	*Nonion laeve*	*Cibicides cassivelauni*	*Cibicidoides alleni*	*Spiroplectammina thanetana*	*"Nodosaria" latejugata*	*Cibicides lobatulus*	*Hazelina thanetensis (ostracod)*
THANET	PB16					◉					◉	◉		◉				○		●	●	●	○		○	○	○	○	○		●	●	■	◉	●	○
	PB15																																			
	PB13		○		○						○	○	○							●	●	◉	○			○	○	○	◉	○	◉	○				
HOVERPORT SECTION																																				
BEACH SECTION																																				
THANET	PB12		○		○								◉																							
	PB11					●				◉	◉	◉		■	■	○	◉	●	○	◉	○	○	○	○	◉	○										
	PB10		○									○	○																							
	PB9	●																																		
	PB8		◉	○	◉					■	○																									
	PB7				○		○	○	◉																											
	PB6				○	○																														
	PB5		○	○																																
	PB4		◉	○																																
	PB3	●																																		
CHK	PB2	●																																		

DISTRIBUTION OF FORAMINIFERA IN THE HERNE BAY (RECULVER) SECTION, KENT

Vertical scale in metres

FORMATION: THANET | ? | WOOLWICH

LITHOLOGY (Schematic)

SPECIES ○ =present (1-4) ◉ =common (5-9) ● =v.common (10-25) ■ =abund. (25+)

SAMPLE	RC23	RC18	RC17	RC16	RC15	RC14	RC13	RC12	RC11	RC10	RC8	RC7	RC6	RC3
Hazelina thanetensis (ostracod)	○				?	○		○						
Spiroplectammina thanetana	●		○	●	●	●	●	●						
Cibicides cunobelini	■		■	■	■	■	■	■						
Cibicides mariae	■		■	■	■	■	■	●						
Anomalinoides nobilis	○		○											
Cibicides cassivalauni	◉		◉	◉	●	◉	○							
Protelphidium hofkeri	◉		◉	◉	○	○	○	◉						
Guttulina problemma	○		○	○	○	○	○	○						
Cibicides cantii	○		○	◉	◉	○	●	◉						
Bulimina trigonalis	○		○		○		○							
"Nodosaria" latejugata	○		○		○									
Heterolepa pegwellensis			○	○	○									
Pullenia quinqueloba			○					○						
Reworked Late Cretaceous Foraminifera			○		○	○								
?Pararotalia sp.			○		○	○								
?Glandulina laevigata			○	○				○						
Globulina ampulla			○		○	○	○	○						
Epistominella vitrea			●	◉	◉		○	○						
Sigmomorphina soluta			○											
Cibicidoides alleni			○											
Cibicides succedens			○			○					?			
Asterigerina aberystwythi			○	◉	○		○							
Pulsiphonina prima			?											
Nonion applinae				○	○	○	○	○						
Nonion laeve				○										
Nonionella cretacea				○										
Eouvigerina aculeata (reworked)				○		○								
Bolivina incrassata (reworked)				○										
?Morozovella pseudobulloides (reworked)				○				○						
?Cyamocytheridea magna (ostracod)				○										
?Praeglobobulimina ovata				○				○						
Bolivinoides laevigatus (reworked)					○									
?Subbotina triangularis							○							
Gyroidinoides danvillensis var. gyroidinoides							○							
Coscinodiscus sp. (pyritised)								○						
Recurvoides sp.										○				
Barren of Microfauna												○	○	
?Planorotalites chapmani														○

DISTRIBUTION OF FORAMINIFERA IN THE KERTEMINDE MARL, DENMARK

SPECIES ○ =present (1-4) ⊙ =common (5-9) ● =v.common (10-25) ■ =abund. (25+)

Vertical scale in metres

FORMATION SELANDIAN (=THANET)

LITHOLOGY (Schematic)

SAMPLE	LC1	LC3	LC8
Bulimina trigonalis	●	○	⊙
Gavelinella beccariiformis	■	■	■
Lenticulina turbinatus	⊙	⊙	⊙
Lagena geometrica	○		
Bulimina midwayensis	○	⊙	
Matanzia varians	○		
Pullenia quinqueloba	⊙		○
Dentalina colei	⊙	●	⊙
Dentalina plumerae	○	○	○
Dentalina glaessneri	○		○
Alabamina solnasensis	○		
Cibicidoides succedens	⊙	●	⊙
Gyroidinoides angustiumbilicatus	○		
Lenticulina klagshamnensis	○	○	○
Astacolus hartingi	○	○	○
Globorotalia spp.	○	○	
Guttulina problema		○	○
Astacolus sp. nov.		○	
Cibicidoides alleni		⊙	○
Alabamina obtusa		○	
Globigerina (aff. "ciperoensis")		○	
Glandulina laevigata		⊙	⊙
"Globigerinelloides?" spp.			○
Frondicularia tenuissima			○
Nodosaria latejugata			?
Lamarkina paleocenica			○
Nonionella cretacea			○
Cibicides spp.			⊙

DISTRIBUTION OF FORAMINIFERA IN THE STEVNS KLINT SECTION, DENMARK

SPECIES ○ =present (1-4) ◉ =common (5-9) ● =v.common (10-25) ■ =abund. (25+)

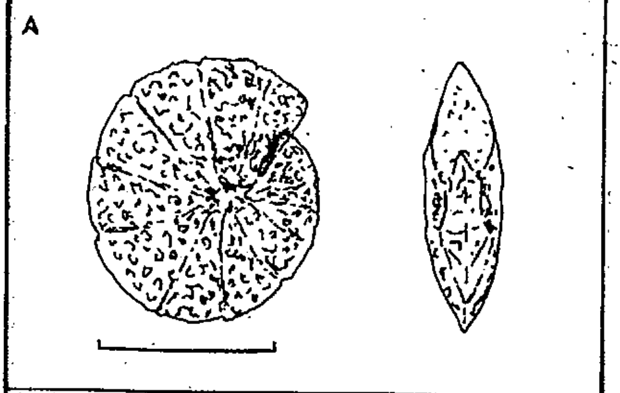
Vertical scale in 0.5 metres


LITHOLOGY (Schematic)

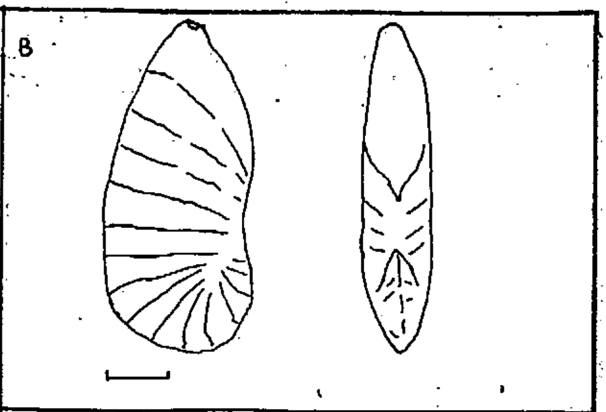
SK1	SK3	SK5	SK6	SK7	SK8	SK9	SK11	SK13	SK16	SK18	SK19	SAMPLE
MAASTRICHTIAN		F	DANSKE KALK									FORMATION
■	■	○	○	●	○	○						*Heteohelix spp.*
●	●											*Globigerinelloides prariehillensis*
●	◉											*Hedbergella holmdelensis*
○	○			○				◉	◉	◉	○	*Guembelitria triseriata*
○												*Reusella szajnochae szajnochae*
○			○	○		○						*Eouvigerina aculeata*
○	○	?		○						?		*Osangularia navarroana*
○												*Pullenia quinqueloba.*
●	○	?	◉		○	●	○	○				*Gavelinella ex gr. voltziana*
?												*Rugoglobigerina spp.*
◉	○											*Praebulimina laevis*
○	○		?									*Cibicides beaumontianus*
○												*Quadrimorphina allomorphinoides*
○			○			○						*Lenticulina spp.*
○	○	?	○									*Stensioeina pommerana*
○												*Bolivinoides decoratus*
○	○			?								*Bolivina incrassata*
		◉	●	●	○	◉		○	○			*?Gavelinella / Cibicides spp.*
		○	○									*Stilostomella spp.*
		?		?			?			○		*Bolivinoides paleocenicus*
			◉	○								*Tappanina selmensis*
			?									*Cibicides tenellus*
			○									*Glomospira charoides*
			○									*Pullenia quaternaria*
				○	■	○	■	■	■	■	■	*Morozovella pseudobulloides*
				○	◉	?						*Morozovella cf. pseudobulloides*
				○								*Chiloguembelina spp.*
				?		○		◉	●	●	○	*Globoconusa daubjergensis*
				◉	◉	●	■	■	■	■	●	*Indeterminate (small, prly pres.) planktonics*
					?		?	○	○	◉	○	*Subbotina tiloculinoides*
						○	○	◉	○	◉	○	*Eoglobigerina trivialis*
						○		○				*Eoglobigerina aff. trivialis*
						◉	◉	○	○	◉	○	*Eoglobigerina eobulloides simplicissima*
						●	■	●	●	■	◉	*Eoglobigerina eobulloides "group"*
						◉	■	●	◉	●	◉	*Eoglobigerina edita "group"*
							○					*Lagena inornata*
								○				*Rosalina squamiformis*
										○		*Marginulina spp.*

Appendix 2: Plates

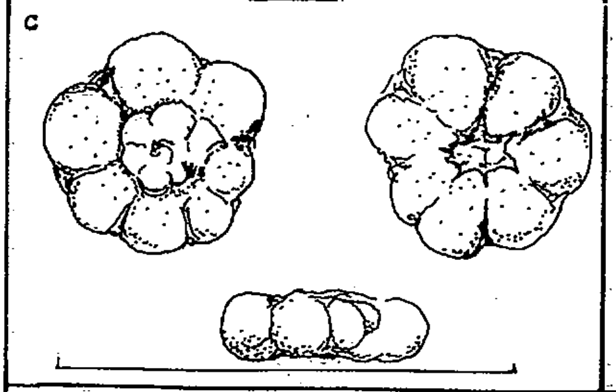
As discussed in the systematics chapter, the vast majority of taxa recorded in this study are well known and have been previously illustrated many times. Therefore illustrations of all taxa described herein are not provided. However, drawings of those taxa less commonly recorded / illustrated from European sections, or of taxa provisionally designated as "new" are given in the following two plates.



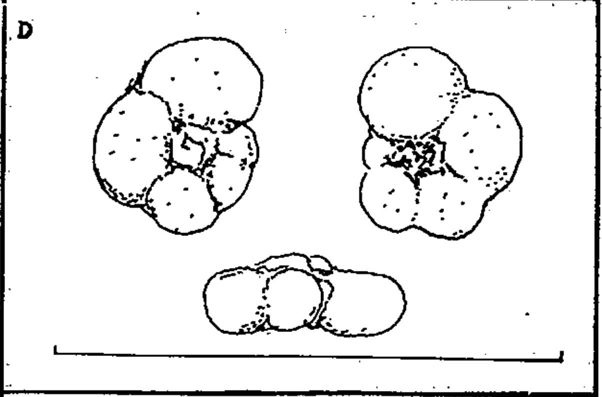
Reticulophragmium amplectens subsp.A *sensu* King



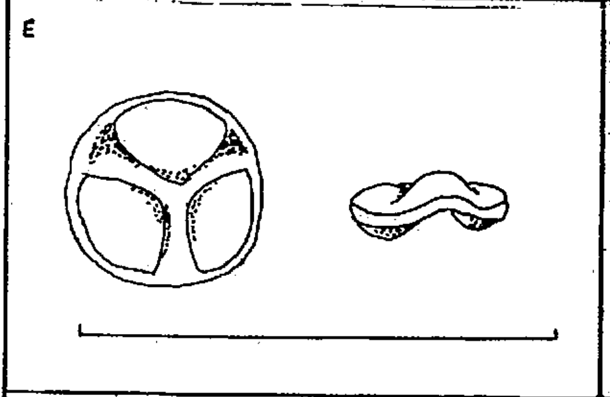
Astacolus ?sp.nov.



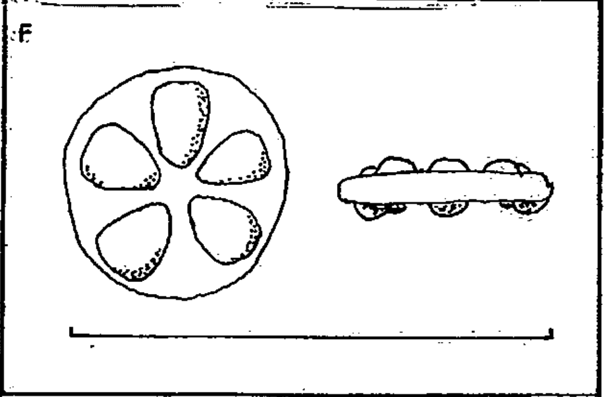
Globorotalia sp.A ?sp.nov.



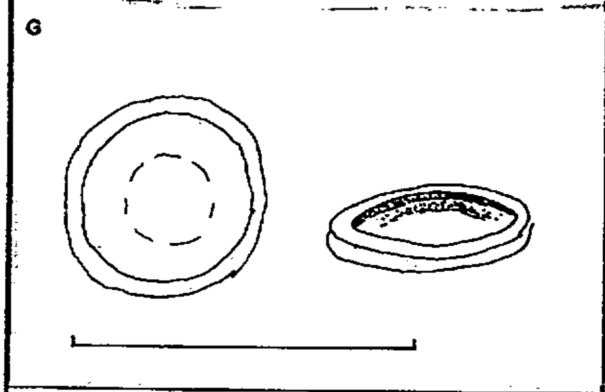
Globorotalia sp.B ?sp.nov.



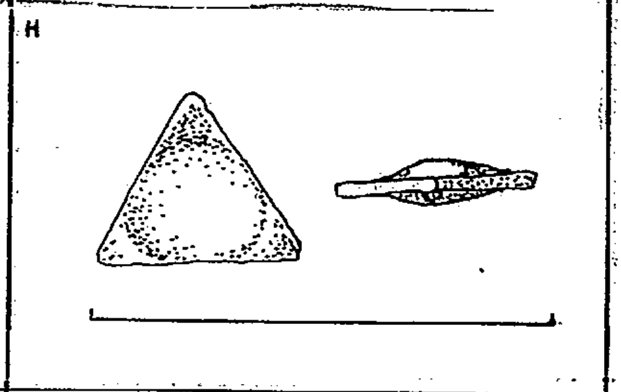
Coscinodiscus sp.8 *sensu* G.S.S.



Coscinodiscus sp.16 *sensu* G.S.S.

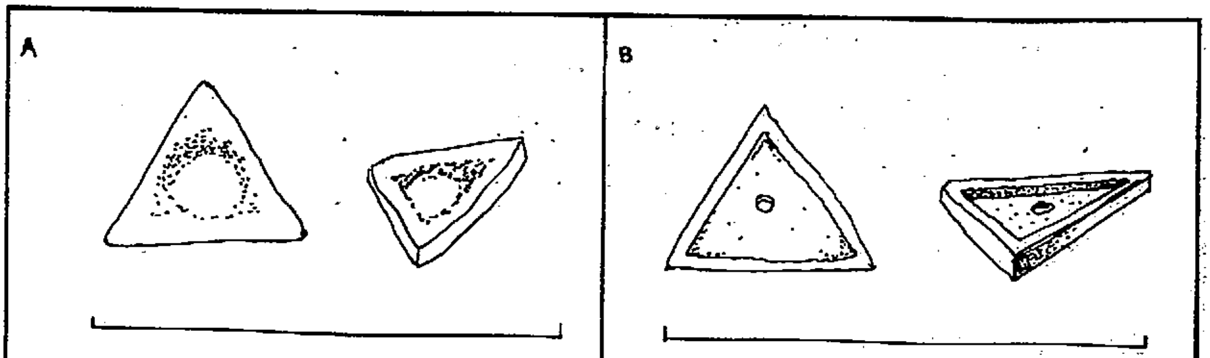


Coscinodiscus sp.20/26 *sensu* G.S.S.



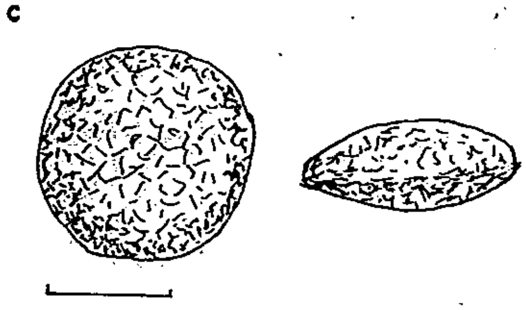
Triceratium cf. *T.abyssorum*

PLATE 1 (scale bar = 0.5mm)



Triceratium sp.1 *sensu* G.S.S.

Triceratium sp.3 *sensu* G.S.S.



Cenosphaera lenticularis

D

E

F

G

H

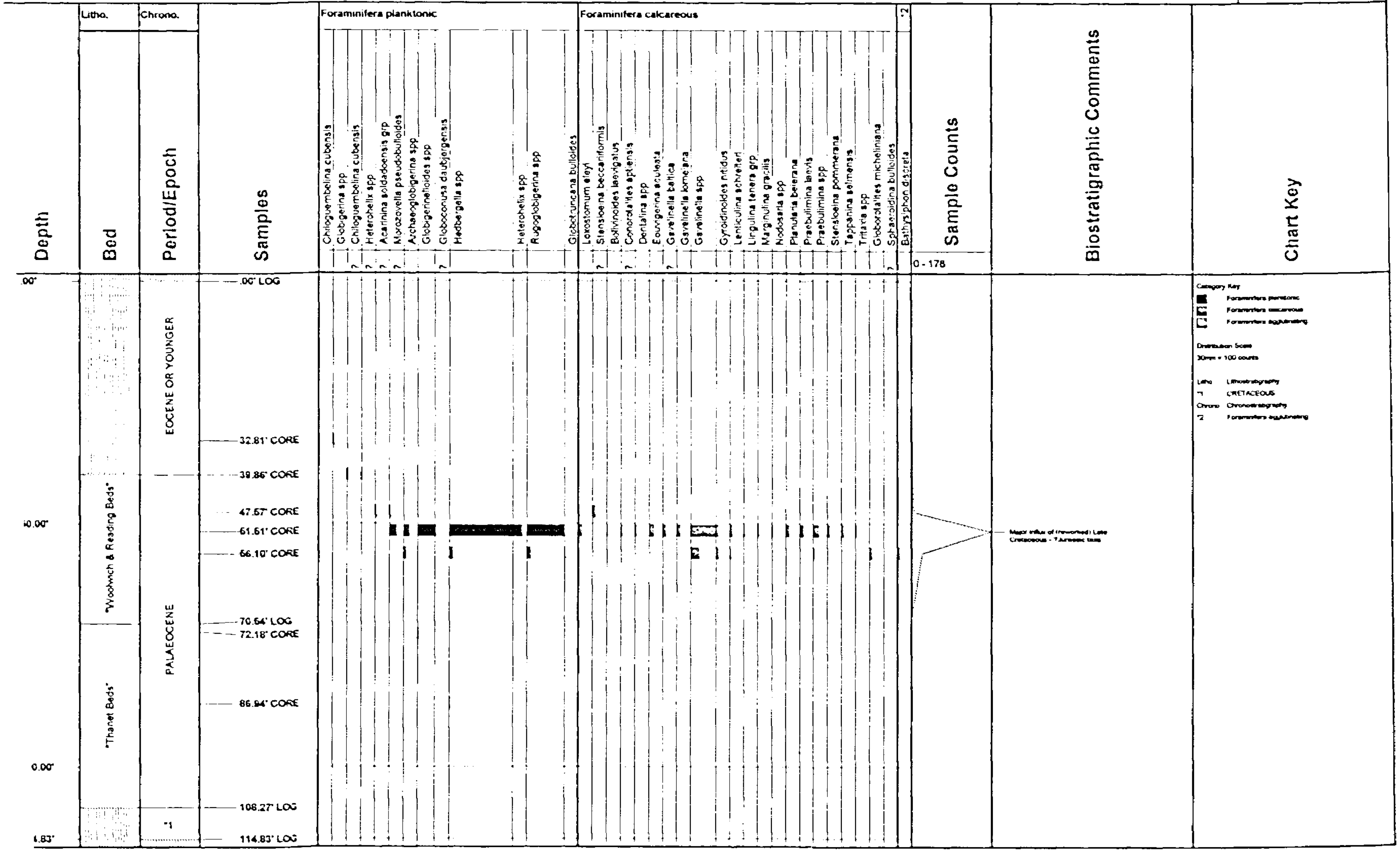
PLATE 2 (scale bar = 0.5mm)

Well Name : Wormingford Mere
Operator : B.G.S.
Interval : 0.00' - 114.83'
Scale : 1:250

Style : Numeric Abundance Histogram
Author : Mike Bidgood (GSS)
Date : 6-April-1996

Micropaleontology Distribution

G.S.S.
Aberdeenshire

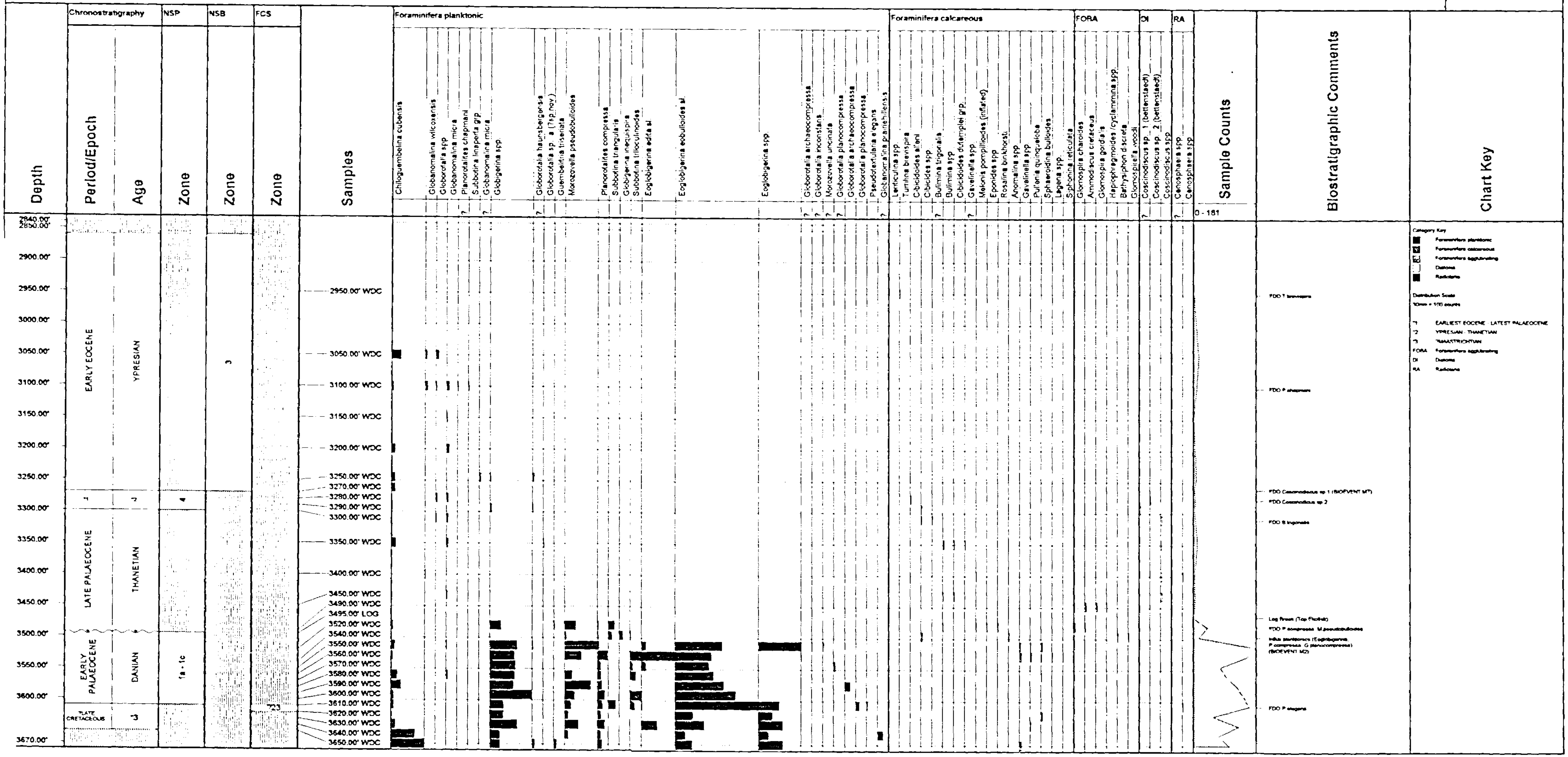


Well Name : 21/26-1D
Operator : Shell / Esso
Interval : 2840.00' - 3670.00'
Scale : 1:1500

Style : Numeric Abundance Histogram
Author : Mike Bidgood (GSS)
Date : 5-April-1995

Micropaleontology Distribution

G.S.S.
Aberdeenshire



Well Name : 29/25-1
Operator : Shell/Esso
Interval : 5780.00' - 6170.00'
Scale : 1:1000

Style : Numeric Abundance Histogram
Author : Mike Bidgood (GSS)
Date : 6-April-1996

Micropaleontology Distribution

G.S.S.
Aberdeenshire

Well Name : 44/2-1
Operator : Shell/Esso
Interval : 2700.00' - 3100.00'
Scale : 1:750

Style : Numeric Abundance Histogram
Author : Mike Bidgood (GSS)
Date : 5-April-1995

Micropaleontology Distribution

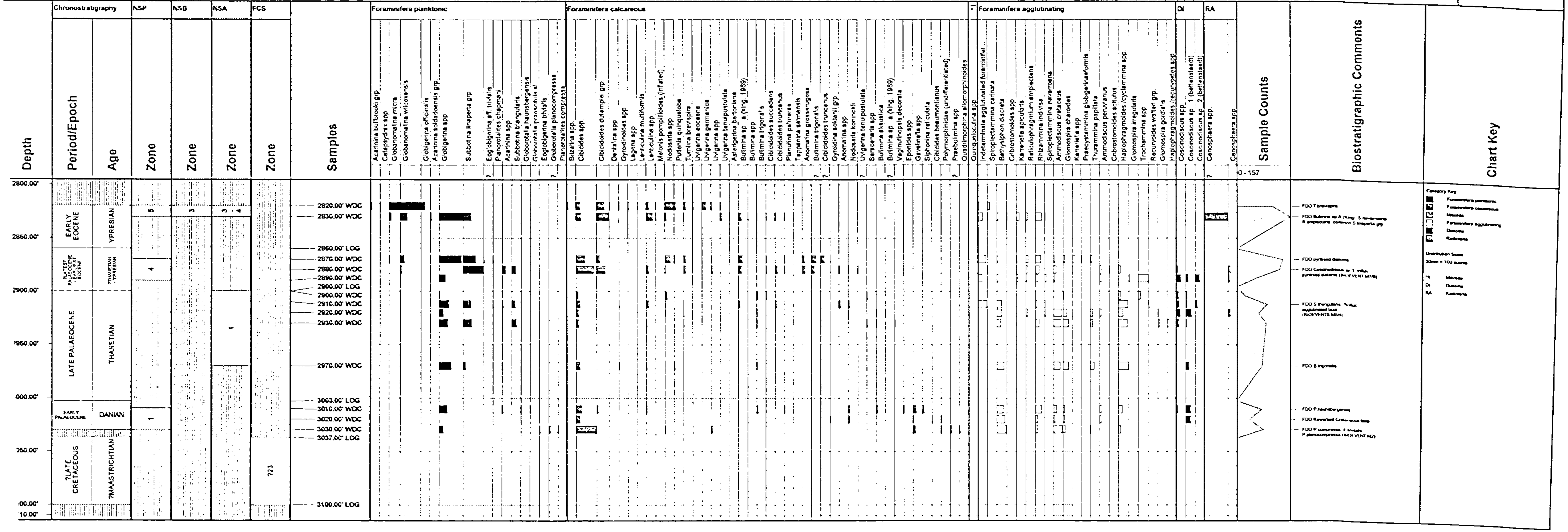
G.S.S.
Aberdeenshire

Well Name : 49/10-1
Operator : Shell/Esso
Interval : 2800.00' - 3110.00'
Scale : 1:750

Style : Numeric Abundance Histogram
Author : Mike Bidgood (GSS)
Date : 5-April-1996

Micropaleontology Distribution

G.S.S.
Aberdeenshire

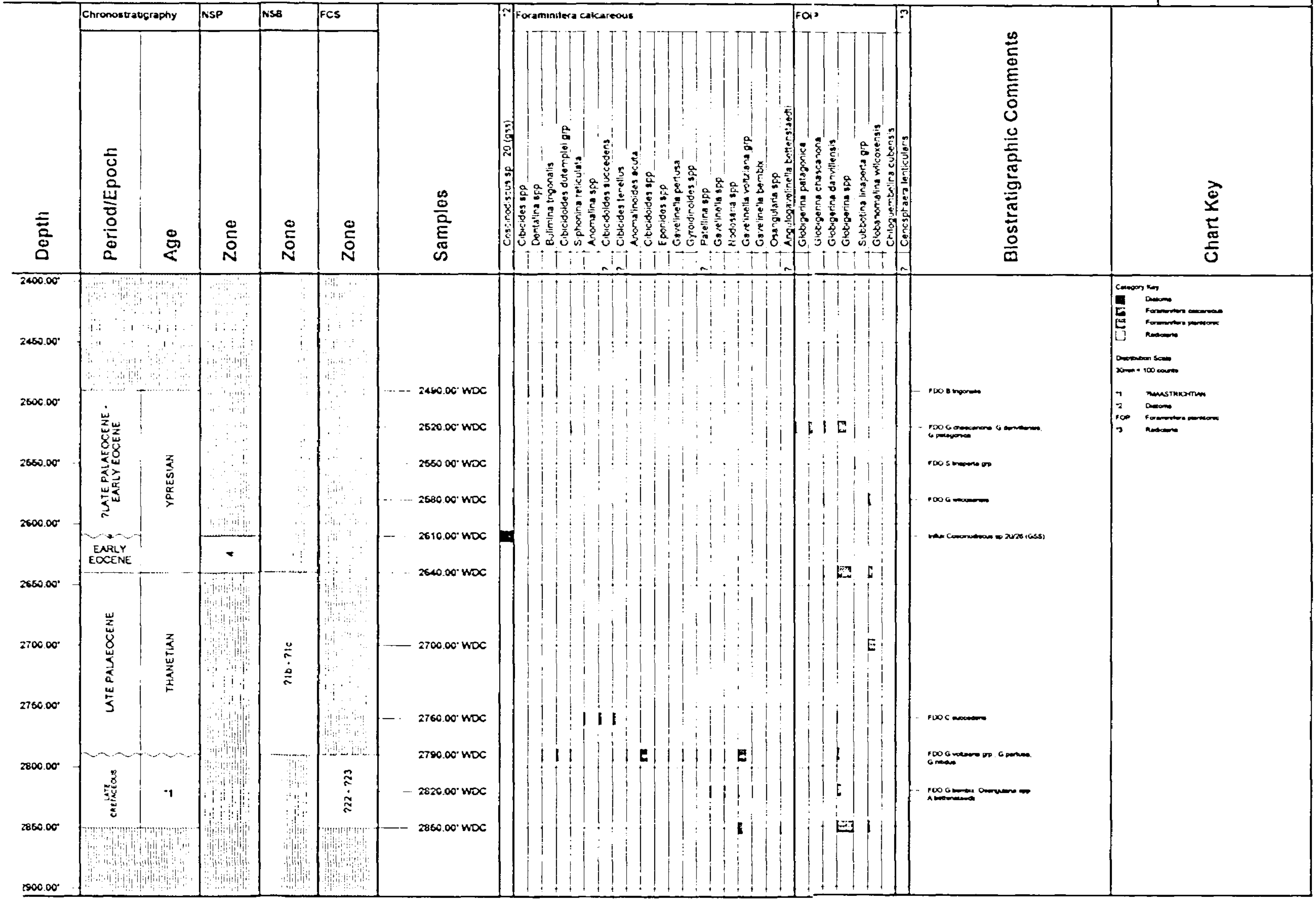


Well Name : 49/20-2
Operator : Shell/Esso
Interval : 2400.00' - 2900.00'
Scale : 1:1000

Style : Numeric Abundance Histogram
Author : Mike Bidgood
Date : 1-August-1996

Micropaleontology Distribution

G.S.S.
Aberdeenshire

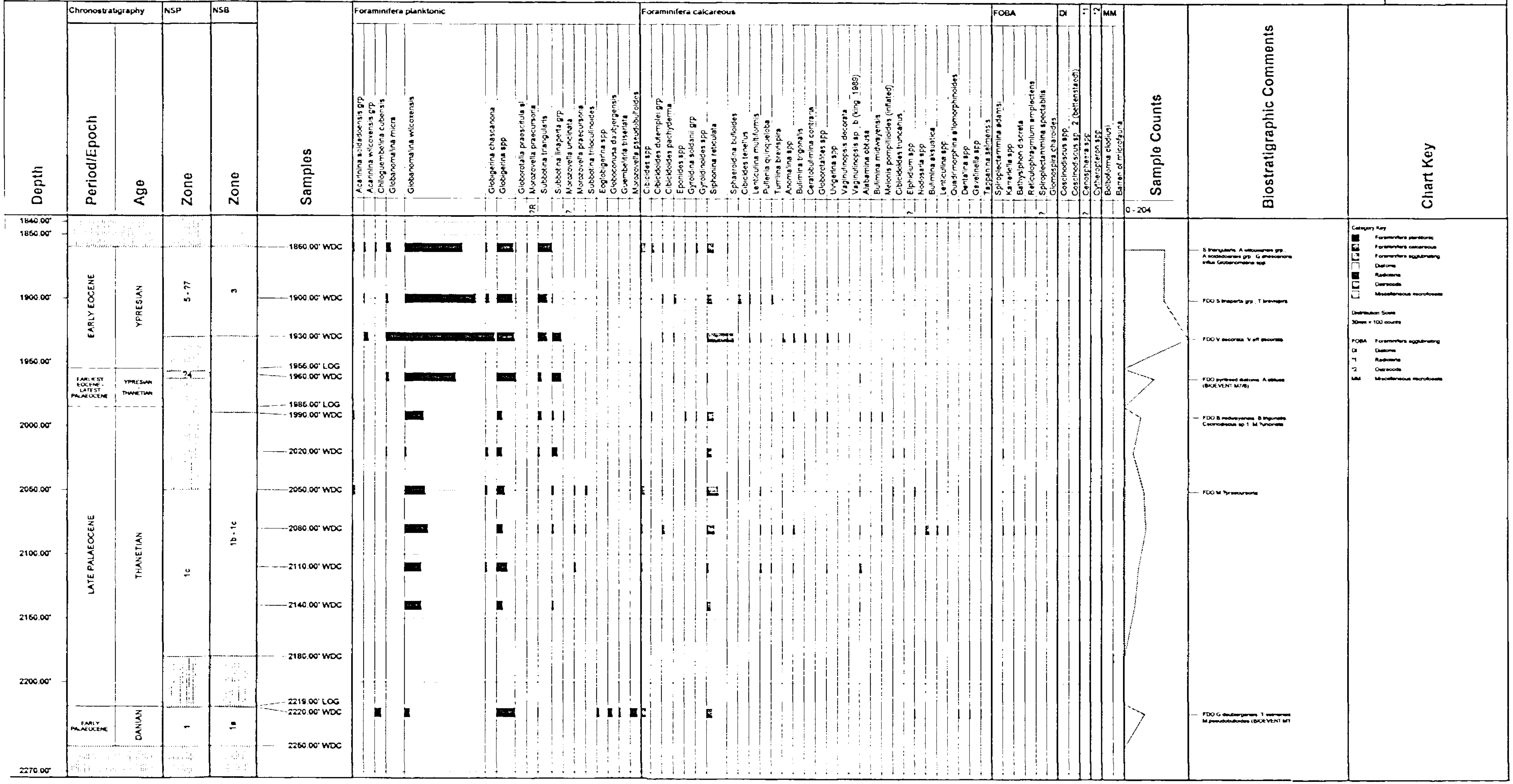


Well Name : 49/24-2
Operator : Shell/Esso
Interval : 1840.00' - 2270.00'
Scale : 1:750

Style : Numeric Abundance Histogram
Author : Mike Bidgood (GSS)
Date : 6-April-1996

Micropaleontology Distribution

G.S.S.
Aberdeenshire

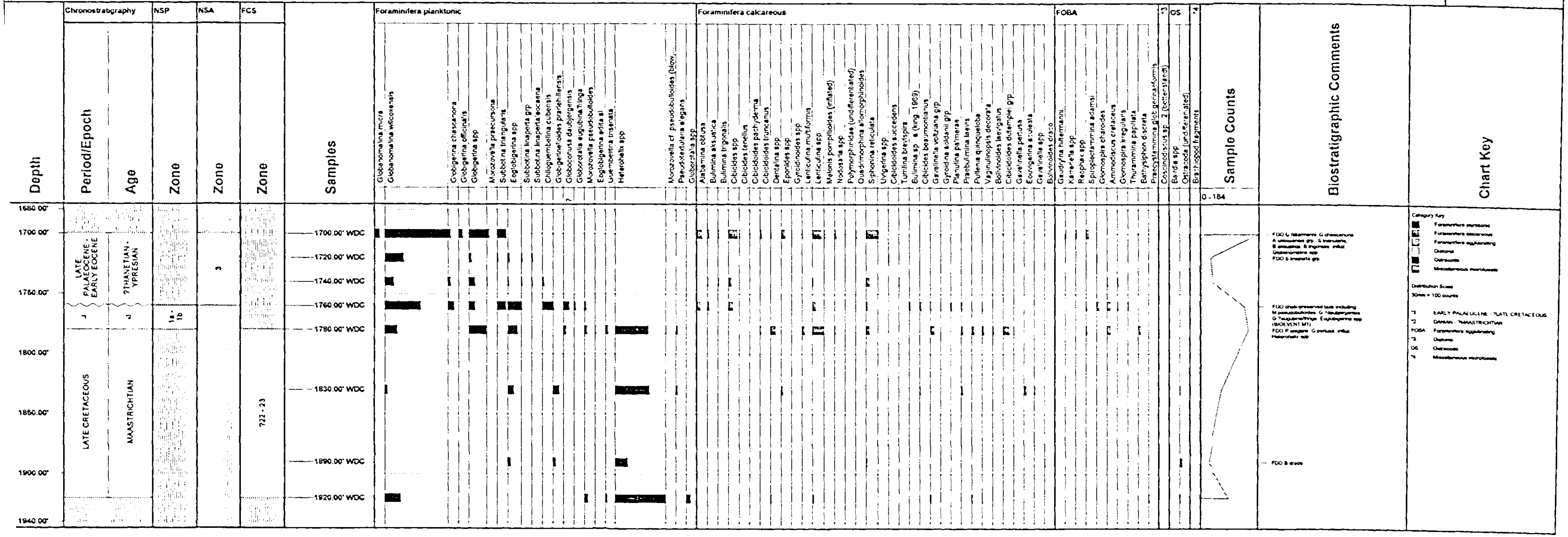


Well Name : 49/24-3
Operator : Shell/Esso
Interval : 1680.00' - 1940.00'
Scale : 1:750

Style : Numeric Abundance Histogram
Author : Mike Bidgood (GSS)
Date : 5-April-1996

Micropaleontology Distribution

G.S.S.
Aberdeenshire

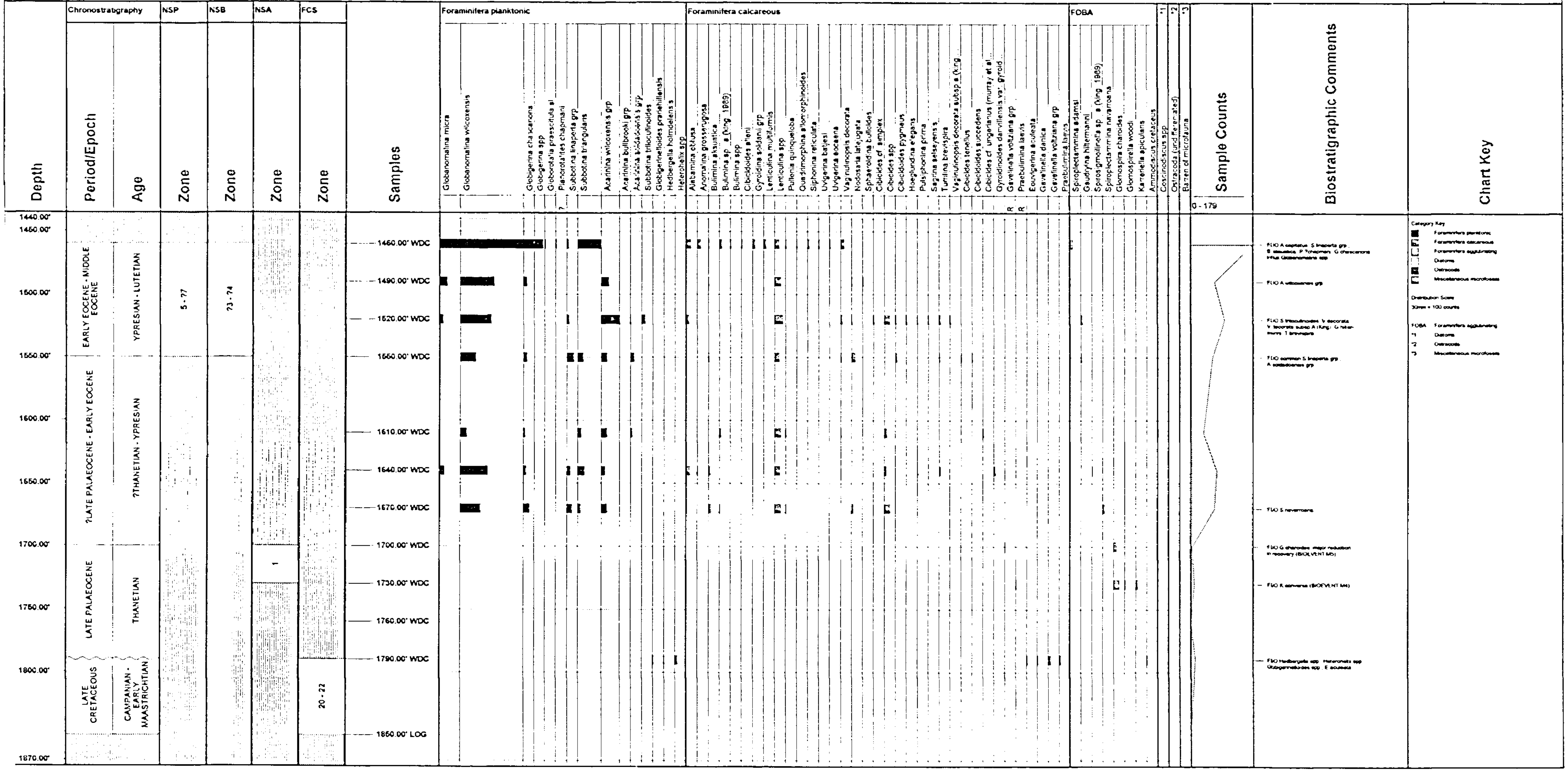


Well Name : 49/24-4
Operator : Shell/Esso
Interval : 1440.00' - 1870.00'
Scale : 1:750

Style : Numeric Abundance Histogram
Author : Mike Bidgood (GSS)
Date : 6-April-1996

Micropaleontology Distribution

G.S.S.
Aberdeenshire



Well Name : 49/25-2
Operator : Shell/Esso
Interval : 2030.00' - 2800.00'
Scale : 1:1500

Style : Numeric Abundance Histogram
Author : Mike Bidgood (GSS)
Date : 6-April-1996

Micropaleontology Distribution

G.S.S.
Aberdeenshire