GEOMAR REPORT

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TERTIARY BENTHIC FORAMINIFERAL
BIOSTRATIGRAPHY
AND PALAEOECOLOGY
OF THE HALTEN TERRACE, NORWAY

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Zusammenfassung

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Four Tertiary wells on the Halten Terrace, Norway are studied and benthic foraminifers and other microfossils analysed. A biostratigraphic scheme with 14 zones based mainly on benthic foraminifers, but also utilising diatoms, radiolarians, planktic foraminifers and bolboforms is proposed for the Tertiary which enables the correlation of the four wells and is applicable for the Norwegian Shelf.

The Tertiary can be broadly divided into three main units on the basis of foraminiferal assemblages:

1. The lower Palaeogene is dominated by agglutinated benthic foraminiferal assemblages.

2. The Oligocene and lower Miocene are dominated by siliceous microfossils with impoverished agglutinated (Oligocene) and calcareous (Miocene) benthic foraminiferal assemblages.

3. The upper Miocene to Pliocene is characterised by increasingly diverse calcareous benthic foraminiferal assemblages.

Palaeoecological interpretations derived from quantitative analyses of benthic foraminiferal distribution patterns and morphogroup analyses outline a succession of palaeoenvironments on the Halten Terrace during the Tertiary. Microfossil diversity and specific distribution appear strongly influenced by tectonic movements, sedimentation rates, circulation patterns and changes in organic flux. The upper Palaeocene is characterised by deep water conditions close to the lysocline with high nutrients and moderate bottom currents. Uplift and a deepening of the CCD may be connected with the opening of the Norwegian Greenland Sea. The Eocene is marked by a return to sub CCD conditions. Biosiliceous sedimentation and deteriorating oxygenation start in the mid Eocene, and continue throughout the Oligocene and lower Miocene, when sea level falls and current activity increases. The mid to upper Miocene heralds the start of improved circulation through the Iceland-Faroe Ridge and the Denmark Strait. In the Pliocene sedimentation rates increase dramatically and a shallowing of the sites occurs during a cooler climatic interval.

Zusammenfassung

Im Rahmen dieser Arbeit wurden benthische Foraminiferenvergesellschaftungen aus vier Bohrungen auf dem Norwegischen Schelf im Bereich der Halten-Terrasse untersucht. Die biostratigraphische Bearbeitung ergab eine stratigraphische Einteilung in 14 Zonen für den gesamten Zeitabschnitt des Tertiärs, basierend auf der stratigraphischen Reichweite von benthischen Foraminiferen, Diatomeen, Radiolarien und Bolboformen. Diese Biostratigraphie ermöglicht die Korrelation zwischen diesen vier Bohrungen und läßt sich grundsätzlich auf entsprechende Sedimente des Mittelnorwegischen Schelfes anwenden.

Das Tertiär kann hiernach auf der Grundlage von benthischen Foraminiferenvergesellschaftungen in drei Hauptabschnitte unterteilt werden:

1. Das untere Paläogen wird durch agglutinierende benthische Foraminiferen charakterisiert.

2. Im Oligozän und unteren Miozän herrschen silikatische Mikrofossilien vor. Gleichzeitig nehmen agglutinierende Foraminiferen im Oligozän deutlich ab, im Miozän wurden nur wenige kalkige benthische Foraminiferenarten gefunden.

3. Im Zeitraum oberes Miozän bis Pliozän nimmt die Anzahl und Diversität kalkiger benthischer Foraminiferenarten deutlich zu.

Palökologische Interpretationen lassen mittels der quantitativen Analyse benthischer Foraminiferenverteilungen und der Analyse von Morphogruppen Rückschlüsse auf das Paläoenvironment der Halten-Terrasse während des Tertiärs zu. Artenvielfalt und -verteilung scheinen stark durch tektonische Bewegungen, Sedimentationsraten, Strömungsbedingungen und Veränderungen im organischen Partikelfluß beeinflußt worden zu sein:

Im oberen Paläozän herrschen hier Tiefwasserablagerungen in der Nähe der Lysokline mit hohen Nährstoffkonzentrationen und nur mäßigen Bodenströmungen vor. Eine Heraushebung des Meeresbodens und ein Absinken der CCD fallen zeitlich mit der Öffnung des Europäischen Nordmeeres zusammen.

Die eozänen Sedimentationsbedingungen spiegeln Verhältnisse unterhalb der CCD wider. Im mittleren Eozän setzt silikatische Sedimentation ein sowie eine geringere Durchlüftung. Diese Bedingungen hielten während des Oligozäns und unteren Miozäns an: Hier fand eine deutliche Absenkung des Meeresspiegels und eine Verstärkung der Bodenströmungen statt.

Seit dem mittleren bis oberen Pliozän konnte ein Austausch der Wassermassen des Nordatlantiks und des Europäischen Nordmeeres über den Island-Farøer-Rücken und die Dänemark-Straße stattfinden. Im Pliozän erhöhten sich die Sedimentationsraten drastisch. Ab dem oberen Pliozän läßt sich die Anzahl und Diversität von Flachwasser-, bzw. tieferlebenden benthischen Foraminiferen mit Meeresspiegelschwankungen korrelieren.

1. Introduction

One of the most rewarding developments in recent years has been the synergistic effect achieved by the close participation between geologists working in diverse fields. The two-stage German-Norwegian geoscientific co-operation to which this research contributes is an example of such a scheme. The first phase of this project, lasting from 1989 to 1992, aimed to investigate and decipher the Cenozoic erosional and sedimentary history of the NW European continental margin and examined the consequences of this for hydrocarbon generation and accumulation by means of a combination of techniques such as seismic stratigraphy, sedimentological and palaeontological analyses of oil well material and geophysical downhole measurements. The GEOMAR group concentrated on the area in the northern North Sea between 61°N and 62°N and 2-4°30'E. The results of this work are summarised in Weinelt (1992) and Steuerbaut *et al.* (1991).

This research is part of the second stage which involves the geological departments of the universities of Oslo, Tromsø, Trondheim, Cologne, Karlsruhe and the Research Centre at Jülich as well as GEOMAR in Kiel. The project, entitled 'Rifted-Sheared Margins - Evolution and Environment', extends work from the first phase further into the Norwegian Sea to the Møre Margin and the Halten Terrace area. It will add to and broaden the information already gathered, and bring about a clearer understanding of the sedimentological and tectonic processes that occurred from the Paleocene to the Pliocene. Apart from the micropalaeontological work carried out here, isotopic and sedimentological studies have also been carried out by Aichinger (in prep.).

For this study the benthic foraminifers present in cuttings from four oil wells in the Norwegian Sea were studied. They are all located on the Halten Terrace area off the coast of Norway.(Fig. 1).

The main objectives of this study are threefold:

1. To create a biostratigraphy for the Halten Terrace area using mainly benthic foraminifers, but also including other microfossils such as radiolarians, diatoms, bolboforms and planktic foraminifera where neccessary.
2. To monitor changes in palaeoenvironments and palaeodepth using foraminiferal morphogroups and relative percentages of the various microfossil groups.
3. To compare the newly created biostratigraphy with other biostratigraphic schemes erected for the same and adjacent areas in order to provide correlations between the various biostratigraphies

Detailed study of the rates of change, variation and of the turnover in the benthic foraminiferal assemblages will not only yield useful information about past benthic foraminiferal communities, but may also provide further clarification on the palaeoenvironmental, hydrographic and tectonic history of the Norwegian-Greenland Sea.
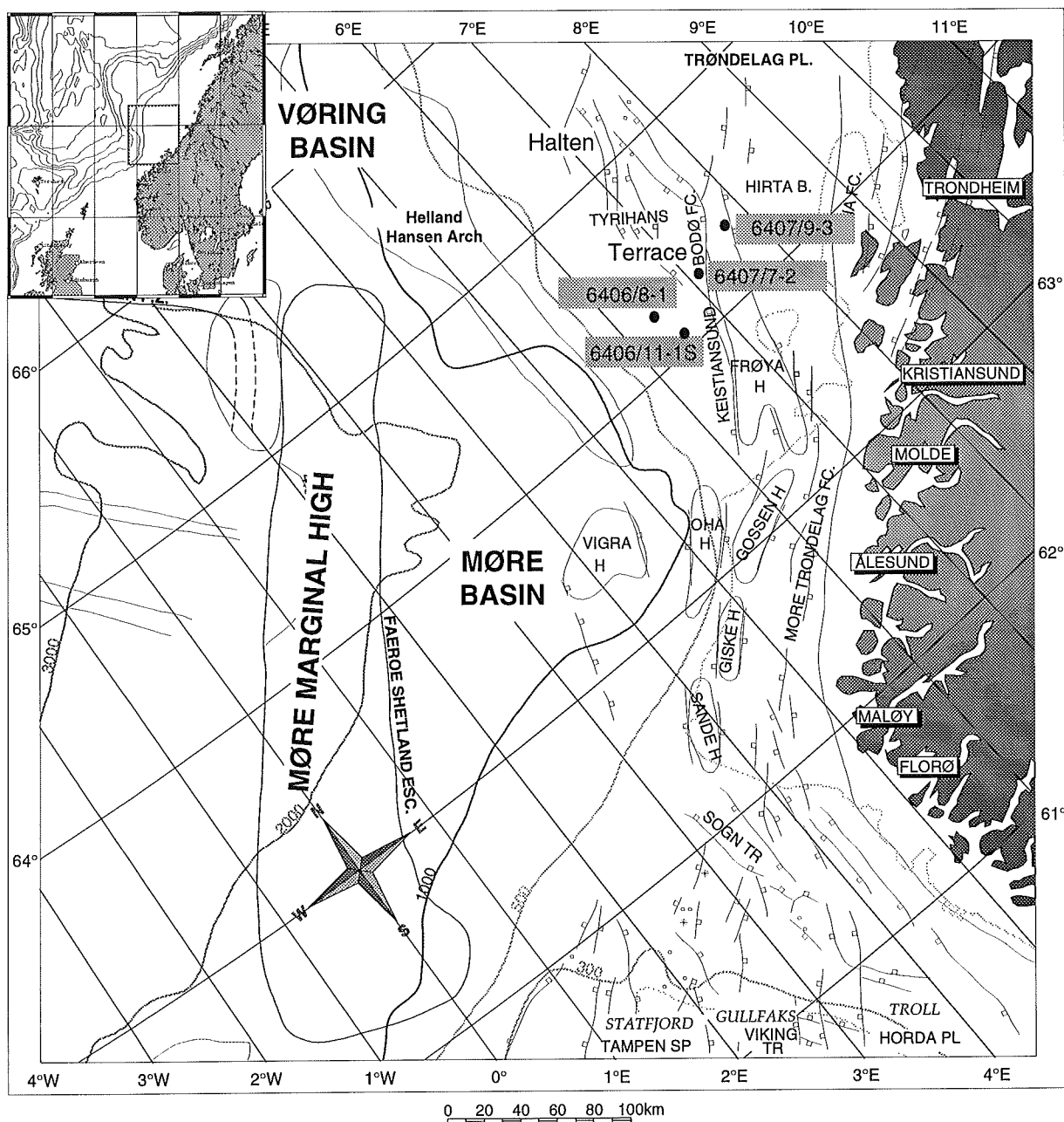
Figure 1. Location of wells on the Halten Terrace.
ESC, escarpment; FZ, fracture zone; FC, fault complex; B, basin; H, High; PL, platform; TR, trough; SP, spur; 300, depth contour (100m).
From Hammer and Hjelle (1984)

2. Background

Although the area concentrated on in this study is the Halten Terrace, a brief overview of the geological setting, tectonic and oceanographic history of the Norwegian Sea is presented in order give a broad perspective of the area, as the processes on the Halten Terrace do not occur in isolation, but are also affected by regional events within the Norwegian Sea and adjacent areas.

2.1 Geological setting

At present the Norwegian-Greenland Sea can be seen as being divided up into a series of sub-basins by a number of morphological features such as fracture zones, ridges and escarpments (Fig. 2). The present day margin area is a Cenozoic feature but much of its post depositional history was determined by its pre-opening structural history (Myhre *et al.*, 1992; Thiede and Myhre 1996b).

The Møre-Trondelag shelf, from about 62°N to 65°N, shows large variations in depth and width and has a relatively steep slope cut by submarine troughs and channels. The southern area in general has depths of less than 200m and is narrow with widths between 60-80km. Further to the north the shelf expands to widths of up to 180-200 km and is also deeper than its southern counterpart, generally having depths greater than 200m. Large depressions and channels of up to 540m are also found (Holtedahl, 1993). The nearby Frøya Bank and Halten Bank are extensive and have minimum depths of 150-100m respectively (Holtedahl, 1993). The Møre-Trondelag and Kristiansund-Bodo fault complexes plus a number a major structural highs also occur in this area (Hamer and Hjelle, 1984).

The nearby Møre Basin lies roughly between 62°N and 64°N and is bounded by the Faroe-Shetland Escarpment on its western side. The Møre Platform to the west of the escarpment is covered by lava flows and sediments Tertiary in age. The Møre Basin has a greatest depth of around 2000m, is largely unstructured and at its central part it contains up to 10km of sediment with around 3.5km being Cenozoic in origin. Most of these are Neogene and Quaternary in age pointing to higher rates of deposition and subsidence during this period (Eldholm *et al.*, 1989), while on the Møre Platform most of the Neogene is missing as the platform probably only subsided to its present depth of 2.5km during the last 2-3my. (Hamer and Hjelle, 1984). In the central area of the basin is the Vigra High towards which onlapping Cretaceous sediments thin, dating this feature as older than early Cretaceous in age. Offlapping sequences from the east indicate that there was prograding sediment build out from the Trondelag Platform during the Tertiary while Quaternary mass flows from the Møre coast have created submarine hills up to 200m high (Hamer and Hjelle, 1984). Northwards the Møre Basin can be seen as a continuation of the Vøring Basin.

The whole region has undergone several rifting phases throughout its history and has been a depositional centre since the Carboniferous (Eldholm *et al.*, 1989). After the Caledonian orogeny there was a period of subsidence and sedimentation, while later Palaeozoic tectonism resulted in a series of rotated fault blocks filled in with sediment. During the late Palaeozoic-early Mesozoic a

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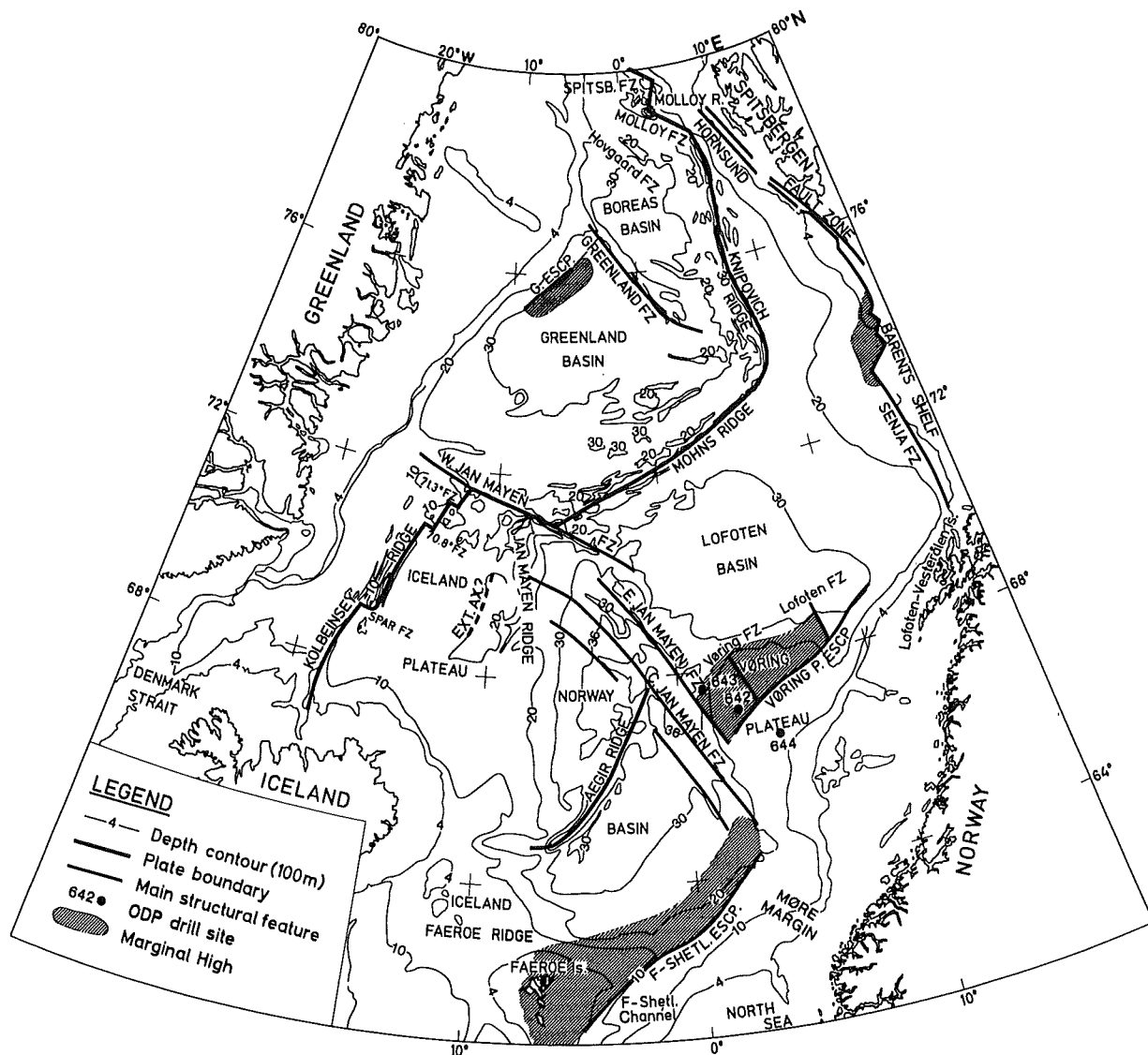
Figure 2. Morphological and structural features of the Norwegian-Greenland Sea.
FZ, fracture zone; P, plateau; ESCP, escarpment; F-SHETL, Faeroe-Shetland; SPITZ, Spitzbergen,
EXT. AX, Extinct axis.
From Eldholm et al. (1989)

general smoothing of relief took place forming a large regional basin in the early Jurassic. Much
of the later Palaeozoic sedimentation has now been lost through later Mesozoic uplift and erosion
(Eldholm *et al.*, 1989).

During the Jurassic and Cretaceous the area underwent a period of extensional tectonism which
caused widespread crustal thinning and rifting. The culmination of these events led to most of the
present series of basins and highs observed today. As a consequence of this crustal thinning and
rifting there was an upwelling of deep mantle material in the area which subsequently, due to
cooling, led to further subsidence in this area (Boen *et al.*, 1984; Eldholm *et al.*, 1989). Tertiary
movements of plate boundaries through the Norwegian-Greenland Sea were preceded by renewed

lithospheric extension in the late Cretaceous and/or early Paleocene (Myhre *et al.*, 1992)

Prior to the opening of the Norwegian Sea, the continental part of the present margin was a shallow epicontinental sea which extended into the North Sea and Barents Sea. (Myhre *et al.*, 1992). During the early Tertiary the opening of the Norwegian-Greenland Sea occurred around the time of the Palaeocene/Eocene boundary at about 57.5Ma (Eldholm *et al.*, 1989; Talwani and Eldholm, 1977). Between Anomalies 25/24B and 13 (about 36Ma) Greenland moved in a NW direction relative to Eurasia. During the earliest Eocene (57-56Ma) the movement was characterised by extensional movement between the Charlie-Gibbs and Greenland-Senja Fracture Zones and dextral shear further north, while during the Eocene plate geometry caused continent to continent translation between Northeast Greenland and Svalbard (Eldholm *et al.*, 1984; Myhre *et al.*, 1992). A regional syn-rift uplift is associated with this event (Stuevold, 1996). At about the time of Anomaly 13 the pole of rotation changed and the relative plate motion changed to west-northwest. This change in the relative spreading direction is associated with the cessation of spreading in the Labrador Sea and the change in the plate geometry, with Greenland becoming part of the North American Plate. This in turn led to the opening of the northern Greenland Sea (Eldholm *et al.*, 1989; Myhre *et al.*, 1992). (Fig. 3)

During the Paleogene, deposition along the rifted margin was dominated by rift induced uplift which gave rise to the erosion of highs and redeposition on the outer Møre and Vøring Basins. Subsidence during the Eocene and Oligocene led to pelagic sedimentation becoming more important, although the highs continued to influence sedimentation until their burial in the late Oligocene (Myhre *et al.*, 1992). Later erosion has meant that on the northern part of the shelf only thin Eocene sequences are seen, while Oligocene sediments are only preserved on Halten Bank (Stuevold, 1996).

Sedimentation during the Neogene and Quaternary is characterised by the outbuilding of sediment on a subsiding margin. During the Miocene and Pliocene there was an increase in sediment supply forming large siliclastic wedges along the present shelf edge topped by glacial deposits. (Myhre *et al.*, 1992). This increase in sediment probably came from erosion of the uplifting Fennoscandia.

The exact timing of this phase of uplift has been much debated. Myhre *et al.*, (1992) postulated that because increased sedimentation can be seen prior to the onset of northern hemisphere glaciation during the Pliocene, the uplift may have begun before glaciation and that glacial erosion and crustal rebound have amplified the magnitude of these sedimentary wedges. Riis and Fjedskaar (1993) suggested that a late Pliocene uplift occurred, depositing large prograding wedges on the whole of the mid-Norwegian shelf, with the uplift being mainly due to isostatic re-equilibrium after glacial erosion. Gravdal (1985) documented a regional uplift on the eastern flank of the Møre Basin from mid Oligocene to Miocene and inferred that this uplift and subsequent erosion supplied large volumes of prograding sediment into the northern Møre basin. Stuevold and Eldholm (1996) recently suggested that in the area 64°N-68°N uplift occurred from the late Oligocene to the Pliocene with uplift being amplified during Pliocene and Pleistocene times due to isostatic rebound from the northern hemisphere glaciation.

Paleocene/Eocene   **Eocene/Oligocene**
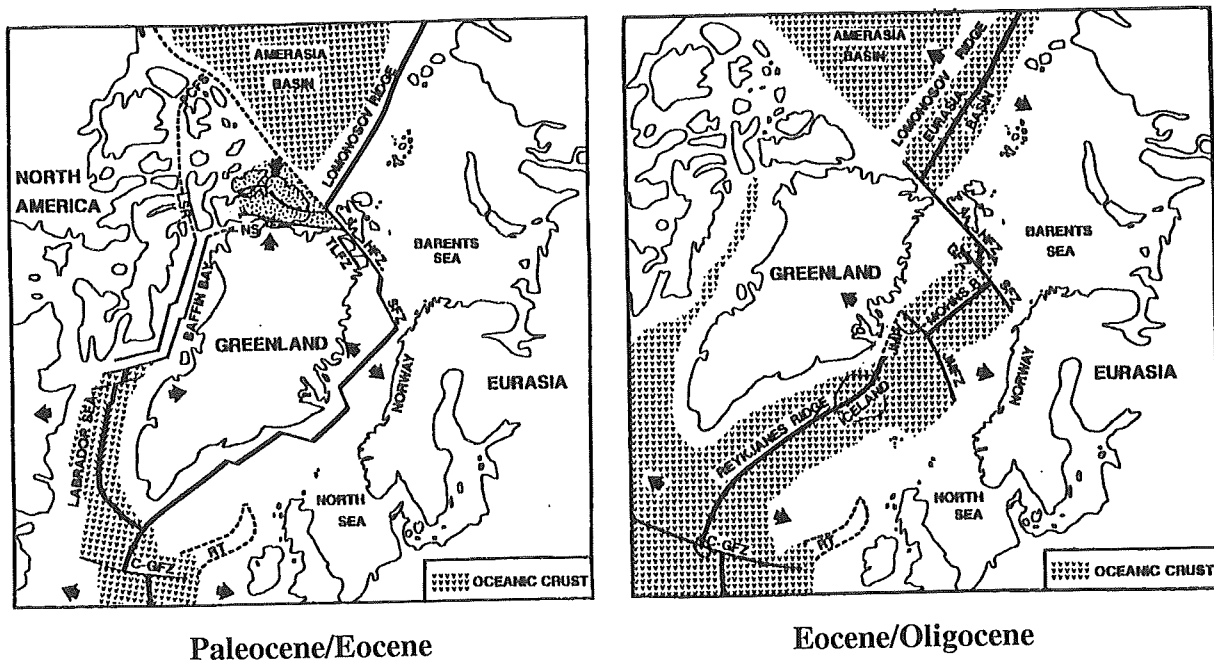
Figure 3. Plate tectonic movements in the North Atlantic region, Paleocene to Oligocene. C-GFZ, Charlie-Gibbs Fracture Zone; JMFZ, Jan Mayen Fracture Zone, SFZ, Senja Fracture Zone; GFZ, Greenland Fracture Zone; PCFS, Parry Channel Fracture Zone; HFZ, Hornsund Fault Zone; TLFZ, Trolle Land Fault Zone; NS, Nares Srait; LSR, JMR, Jan Mayen Ridge; Lancaster Sound Rift; RT, Rockall Trough. Arrows indicate relative plate motion. From Myhre et al. (1992)

2.2 Modern oceanography

Two main current systems control surface circulation in the Norwegian-Greenland Sea today. (Fig. 4). The Norwegian Current - which is formed by North Atlantic Water (NAW) brings relatively warm and high salinity waters from south of the Greenland-Scotland Ridge up to the Arctic. It is centred on the continental shelf of Norway and usually covers the shelf to a depth of around 500m (Mackensen et al., 1985) and fills the deep hollows and submarine fjords along the continental shelf (Holtedahl, 1993). Near Bear Island the current divides: one part flowing north into the Arctic Ocean as the West Spitzbergen Current while the other follows the Barents shelf as the North Cape Current. The East Greenland Current brings cold and reduced salinity Arctic waters into the Norwegian Greenland Sea via the Fram Strait, follows the East Greenland continental margin and enters the North Atlantic through the Denmark Strait. These two very different currents largely control the extreme differences in climate to be found today east and west of the Norwegian Sea (Eldholm et al., 1989; Thiede and Myhre, 1996b). Two large anticlockwise gyres are found between the East Greenland Current and the Norwegian Current, resulting in the advection of Atlantic and polar waters into the central Norwegian Sea (Eldholm et al., 1989).

Paralleling the Norwegian coast a third lower salinity current, the Norwegian Coastal Current runs

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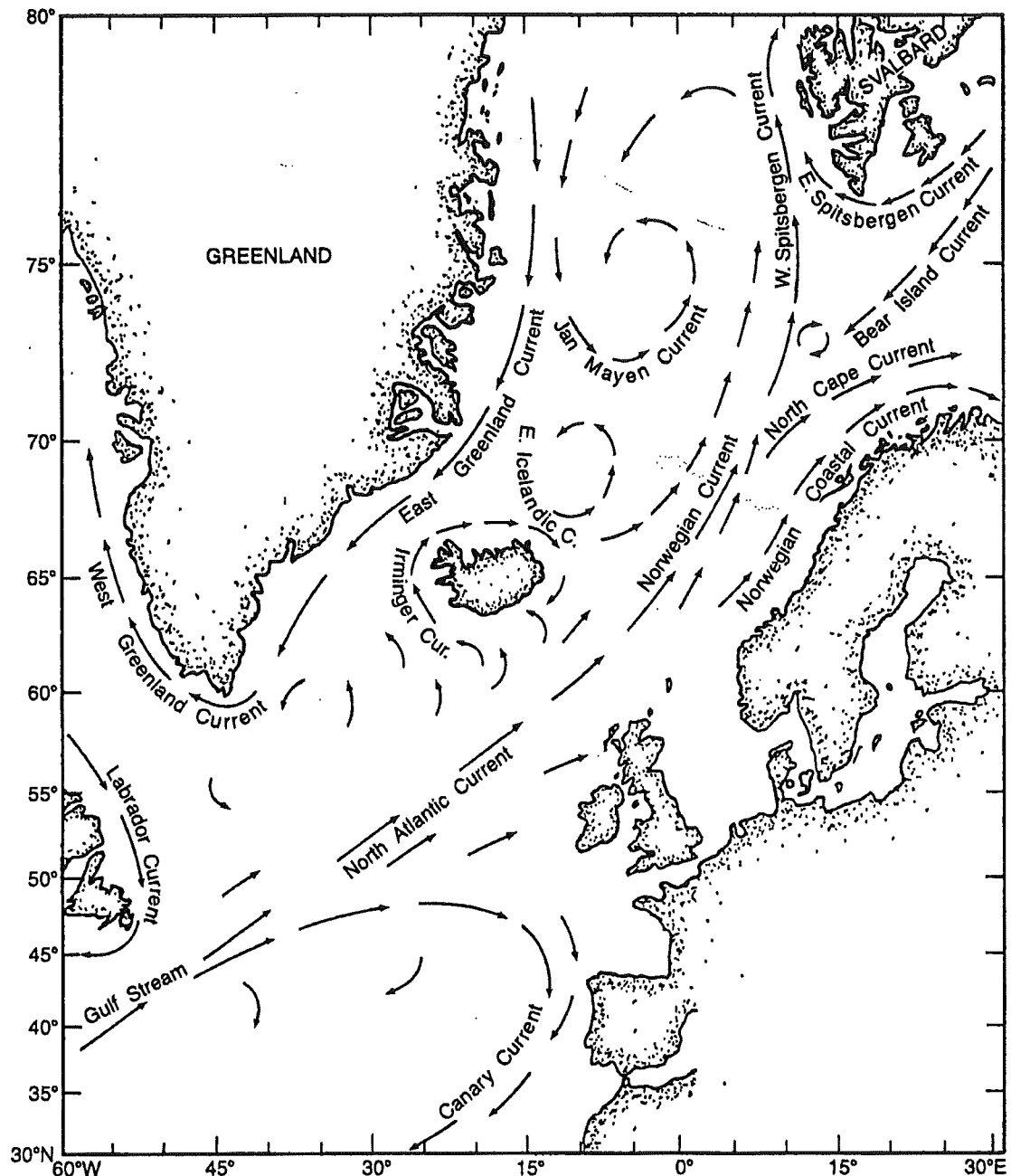
Figure 4. Modern surface currents in the North Atlantic.
From Eldholm et al. (1989)

eastward of the Norwegian Current along the inner shelf. Its offshore boundaries are highly variable and change seasonally, at times extending west of the shelf edge (Eldholm *et al.*, 1989). These surface currents are separated by sharp hydrographical gradients from the deeper cold polar water masses of the main Norwegian Sea (Eldholm *et al.*, 1989; Schrader and Koc Karpuz, 1990; Mackensen *et al.*, 1985). Below the NAW there is a transitional layer of variable thickness which forms a transition to the homohaline (31.91‰) Norwegian Sea Deep Water (NSDW). The transition layer and NSDW together form a roughly 200m layer between the NAW and the homothermal and homohaline Norwegian Sea Bottom Water (NSBW) near the continental margin. These water masses

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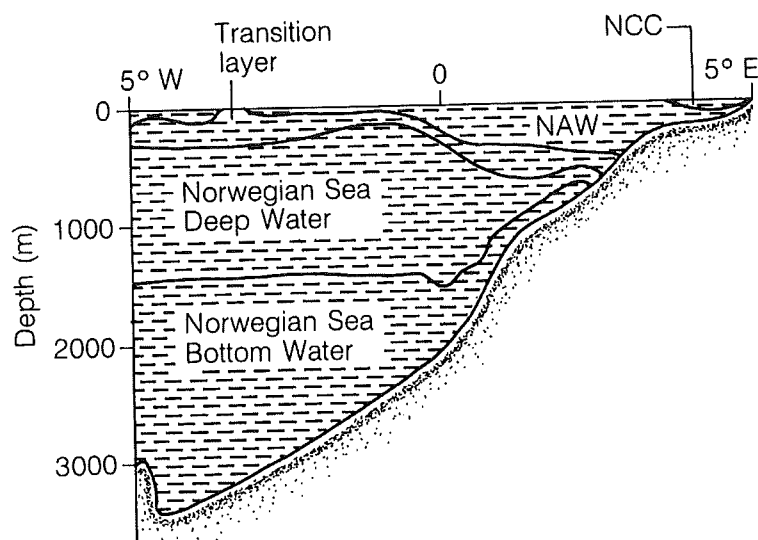
Figure 5. Lateral extent of Norwegian Sea water masses on the Norwegian Shelf. NCC, Norwegian Coastal Current; NAW, North Atlantic Water. From Murray (1991), after Mackensen (1985).

taper towards the continental slope as the permanent pycnocline marking the upper limit of the NSBW is bent upwards in this area (Mackensen *et al.*, 1985) (Fig. 5). The Norwegian Current seen today, probably developed during the late Pleistocene, may have been a factor leading to the deglaciation of Fennoscandia. A similar mode of formation may have occurred several times during the late Pliocene/Quaternary leading to the observed pattern of glacials and interglacials. In contrast there has been a continental ice sheet over Greenland since at least the Last Glacial. (Thiede *et al.*, 1989).

The Norwegian-Greenland Sea today and especially the Greenland Basin is a site of major deep water renewal. Cooling and subsequent seasonal downwelling and cooling of the Atlantic waters cause dense, cold, oxygen enriched waters to form (Bohrmann *et al.*, 1990; Venum *et al.*, 1992). Intermediate water masses from the Iceland and Norwegian Seas - the NSDW pass over the Greenland-Scotland Ridge and through the Denmark Strait and the Faroe-Shetland Channel mixing with Labrador Sea waters and Mediterranean outflow waters to form the North Atlantic Deep Water (NADW) (Bohrmann *et al.*, 1990; Venum *et al.*, 1992). The deep waters of the Norwegian Sea are constrained by the sill depth of the Greenland-Scotland Ridge (about 900m) to circulate internally within the Norwegian Basin (Aagaard *et al.*, 1985). The water that enters the Atlantic as Arctic Bottom Water has been traced around Africa, in the Pacific and Indian oceans (Eldholm *et al.*, 1989: Sy *et al.*, 1997).

2.3 Palaeoceanography

The history of the emergence and submergence of the various sills, ridges and straits surrounding the Norwegian Sea have played an important part in the development of ocean circulation and climate throughout the Cenozoic. Processes such as the submergence of the Greenland-Scotland Ridge and the opening of the Fram Strait have allowed the formation of NADW, initiated the ocean wide exchange of waters through the system of currents observed today and influenced the climates of Greenland and Northern Europe (Eldholm et al., 1989; Myhre and Thiede, 1995).

The Fram Strait provides the only passage between waters of the Arctic and the Norwegian-Greenland Sea. Although it was probably open as a shallow passageway from the late Oligocene, it was probably not until the mid Miocene that it reached sufficient depth (around 2km) to allow deeper waters from the Arctic into the Norwegian Sea (Kristoffersen, 1990). However Myhre et al. (1995) preferred a mid Miocene age for first deep water overflow . From sedimentary evidence it seems that no great change in current regimes has taken place through the gateway since it first opened (Kristoffersen, 1990).

Up until the early Mid Miocene it seems likely that very little or no abyssal water exchange took place into the main North Atlantic - the Greenland-Scotland Ridge acting as a barrier to deep water exchange. However, eastern parts of the ridge i.e. the Faroe-Shetland Channel may have been below sea level during the Eocene to at least bathyal depths as similar benthic foraminiferal assemblages have been reported from both the Norwegian and Labrador Seas (Kaminski et al., 1990). Eocene bottom waters were probably relatively warm with little current activity taking place (Miller, 1994; Miller and Tucholke, 1983). During the Paleocene and Eocene surface water connections may have existed with the North Atlantic as witnessed by the presence of temperate to subtropical siliceous faunas and floras recorded during ODP Leg 151 (Thiede and Myhre 1996a). Cool to temperate waters probably first appeared during the late Oligocene to early Miocene (Thiede and Myhre 1996a).

Deep water and abyssal overflow across the Greenland-Scotland Ridge probably did not take place until the mid to late Miocene, about 13-11Ma. and occurred first across the Iceland-Scotland segment of the ridge (Bohrmann et al., 1990). This seems to have occurred contemporaneously with an increase in drift sedimentation in the North Atlantic and with major hiatus formations (Bohrmann et al., 1990; Eldholm et al., 1989). Benthic foraminiferal evidence from the North Atlantic (Rockall Plateau) and the Norwegian Sea also indicates that overflow began during the Mid Miocene around 15 - 13Ma, as at this point a number of species that had persisted since the Oligocene became extinct and several new species appeared amongst the foraminiferal assemblages. The assemblages also change in character from those heavily dominated by agglutinated species to more calcareous rich assemblages. At the same time rapid growth of the ice sheet in Antarctica and a marked change in the carbon and oxygen isotope properties of deep sea foraminifers world-wide have been noted (Schnitker, 1986; Osterman and Qvale, 1989; Poole and Vorren, 1993).

Overflow through the Denmark Strait probably began during the late Miocene about 7.5-7Ma, and is contemporaneous with the onset of drift sedimentation on the Eirik Ridge (Bohrmann et al., 1990, Wold, 1992) and with a change in the benthic foraminiferal assemblages at Site 646 in the Labrador Sea from a low abundance predominantly calcareous fauna more indicative of Antarctic bottom water to higher abundance mixed assemblages of calcareous and agglutinated taxa thought to be typical of NADW (Srivastava et al., 1987). Schnitker (1986) also noted a change in benthic foraminiferal assemblages around 6.5-7Ma and linked this change to the Messinian Crisis caused by the closure of the Mediterranean.

During the early Pliocene (4.8-4Ma), using evidence from silica and carbonate deposition, it seems likely that there was a strengthening of the Norwegian Current, possibly initiated by the beginning of a cold water current along the east Greenland coast, which led to the first outflow of Arctic water into the North Atlantic (Bohrmann et al., 1990). Around the same time the first Pacific species of dinocysts are found in the Norwegian Sea, which may also have been due to the initiation of an East Greenland type current and also points to a connection between the Arctic and the Norwegian-Greenland Sea (Mudie, 1989).

Fronval and Jansen (1996) reported that the earliest record of glacial conditions in the Norwegian-Greenland Sea is of ice rafted debris (IRD) on the Vøring Plateau at 12.6Ma which implies that glaciers reached sea level during the mid Miocene. The authors further documented small scale glaciations in the Northern Hemisphere from 7.2-6.0Ma.

Further periods of (IRD) in the Norwegian Sea occur at 5.2-5.0Ma, 4.7-4.3Ma, 4.0-3.7Ma and 3.3-3.1Ma (Thiede et al., 1989). Large scale glaciation was firmly established by 2.6Ma and may have been triggered by increased obliquity and precession amplitudes which led to a sharp increase in insolation (Maslin et al., 1995). There may have been a period between 2.5 and 2.6Ma to 1.2Ma with continuous glacial conditions (Thiede et al., 1989). This resulted in the formation of little or no deep water and surface water circulation very different from today (Jansen, 1989; Thiede et al., 1989). Between 1.2Ma and 0.6Ma a transition to a glacial/interglacial pattern began (Thiede et al., 1989). During glacial periods the bottom water may have been stagnant while the interglacials may have been a time of deep water renewal leading to oxygenation and bioturbation (Thiede et al., 1989).

During the Quaternary the Norwegian-Greenland Sea experienced intense fluctuations between glacials and interglacials (Thiede and Myhre, 1996b). Stratigraphic studies have shown that during only a few interglacials was a warm Norwegian current generated (Eldholm et al., 1987 and references therein). In general, Norwegian Sea surface waters were polar or ice covered for much of the Quaternary, although the exact nature and extent of any ice cover is not yet fully known (Eldholm et al., 1989). Between 13ky and 10ky ago a seasonal ice cover may have existed and oxygen enriched waters filled the deep basin, while after this, a situation analogous to that found today may have existed (Eldholm et al., 1989)

2.4 Palaeoclimatology

From the late Mesozoic/early Cenozoic to the mid-late Cenozoic there was a change in climate from temperate to glacial/interglacial with the onset of large scale glaciation in the Northern Hemisphere taking place at around 2.4-2.6Ma. The Greenland-Norwegian Sea along with the neighbouring Labrador Sea played an important part in this global climate change. From palaeotemperature evidence it seems likely that cooling in the Norwegian Sea progressed in a stepwise fashion (Bohrmann *et al.*, 1990).

The early Tertiary was characterised by low latitudinal temperature gradients with a Cenozoic temperature maximum occurring during the early Eocene. Global cooling began during the late Eocene leading to an increase in temperature gradients during the late Oligocene to mid Miocene (Miller *et al.*, 1987; Shackleton and Kennett, 1975), although from silicoflagellate and dinocyst evidence (Thiede *et al.*, 1989) up until 18.7Ma (early Miocene) the Norwegian Sea may have been temperate to subtropical. The limiting of the passage of Arctic waters through the Fram Strait probably affected the early Cenozoic climate in that it helped to promote a period of warmth on the surrounding land masses and seas, leading to a Neogene maximum for land temperatures at around 18-13Ma. This increased erosion and input from the surrounding land areas (Lawver *et al.*, 1990), confirmed by pollen and spore evidence (Mudie *et al.*, 1990).

Following this Neogene temperate period there was a deterioration of climate with a rapid cooling phase leading to the loss of temperate and warm silicoflagellates by the late Miocene (ca. 7.4Ma). Although there may have been a brief warm period just before the Miocene/Pliocene boundary at around 5.5-5.4Ma (Locker and Martini, 1989), the appearance of subarctic Pacific dinocysts at the Miocene/Pliocene boundary and changes in the benthic foraminiferal assemblage composition probably herald the initiation of a East Greenland type current (Mudie, 1989; Poole and Vorren, 1993), with subsequent further cooling of the climate taking place throughout the Pliocene and Pleistocene leading eventually to fully glacial conditions. This agrees with the findings of Bohrmann *et al.* (1990) who also postulated from silica and carbonate depositional evidence that during the early Pliocene (4.8-4Ma) there was a strengthening of the Norwegian Current. This may have been initiated by the beginning of a cold water current along the east Greenland coast, which led to the first outflow of Arctic water into the North Atlantic. There may have been a late Pliocene warm period as documented by evidence from Leg 151 (Spiegler, 1996). This corroborates the evidence of Funder *et al.* (1985) who suggested that NE Greenland was covered with boreal forests during the late Pliocene to Pleistocene.

The period from 2.6-1.2Ma was characterised by large glacial events with no clearly developed interglacial periods. Around 1.6Ma the glaciations became more intense with the ice sheets advancing onto the shelves. There were also regular glacial/interglacial fluctuations possibly reflecting a 100ky cycle (Henrich, 1989; Thiede *et al.*, 1989). Haflidason *et al.* (1991) have postulated that the Norwegian shelf area underwent at least five major glacial periods during the past 1.1my. The interglacials were times of high carbonate accumulation rates and high percentages of

subpolar planktic foraminifers and coccoliths and subpolar to boreal benthic foraminifers (Spiegler and Jansen, 1989; Poole and Vorren, 1993). The interglacials may have been characterised by, or even initiated by, a warm Atlantic current much like the Norwegian Current today (Henrich, 1989).

2.5 Lithology of Cenozoic sediments of the mid-Norwegian shelf

2.5.1 Introduction

The Cenozoic sediments on the Mid Norwegian shelf can be divided into two main units covering the Paleogene and Neogene. The Paleogene sediments consist mainly of claystones and siltstones with some tuffaceous shales, whereas Neogene sediments also contain sandstones, coarse clastics and glacio-marine sediments.

The lithostratigraphic units used in the mid-Norwegian area were formally described by Dalland *et al.* (1988). Prior to this a mixture of informal and formal names was used. Many of the formations and groups described can be traced over much of the mid-Norwegian area. (Fig. 6).
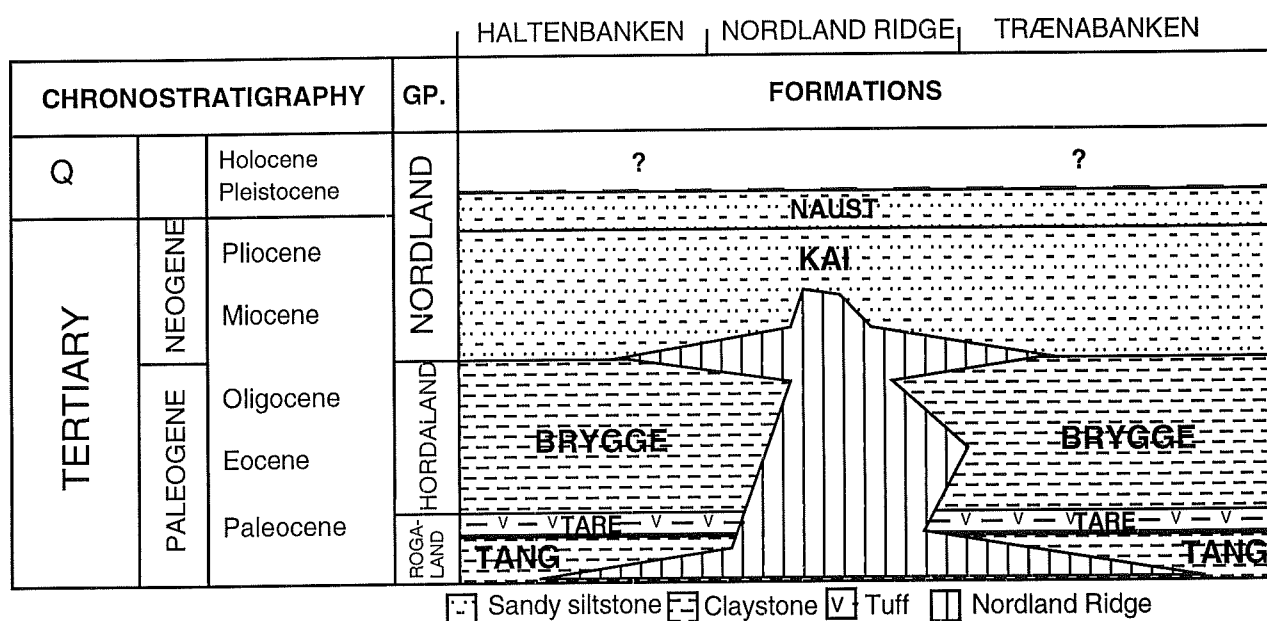
Figure 6. lateral extent of lithologies on the Mid-Norwegian Shelf. Q, Quaternary; GP, Group. From Dalland et al. (1988)

The lithological names used in this study are taken from the completion logs for each well and are themselves a mixture of formal and informal names. In addition, the Sele and Lista Formations, part of the Rogaland Group in the North Sea, although used to describe the lithology in well 6407/9-3, are usually used to describe sediments from the Norwegian North Sea. Table 1 shows the formally defined names and the equivalent informal ones. Table 2 summarises the units ages, lateral extent and depositional palaeoenvironments.

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	GP.	FORMATION		EARLIER USED INFORMAL DIVISIONS
Q	NORDLAND	NAUST − − − − − − −		SULA GP.
TERTIARY	NORDLAND	KAI	SKILLINA GP.	KORGEN
TERTIARY	HORDALAND	BRYGGE	SKILLINA GP.	NARVIK
TERTIARY	ROGALAND	TARE	SKOMVÆR GP.	BALDER/ALSTAHAUG
TERTIARY	ROGALAND	TANG	SKOMVÆR GP.	BODØ

Table 1. Formal and equivalent informal names of lithostratigraphic units in Mid-Norway.
GP., group; Q, Quaternary.
From Dalland et al. (1988)

2.6 Brief description of well lithologies

2.6.1 Well 6406/8-1

Fig. 7 shows the general lithology of Well 6406/11-1. It consists of two main units. From 2800m to about 1400m siltstones, claystones and shales are mainly present with occasional sand layers and limestone stringers. From 2330m onwards pyrite, glauconite, micas and lignite, usually in trace quantities, are also found. From 1400m onwards there is a marked increase in the >63μm fraction and the lithology consists mainly of unconsolidated sands. This is reflected in the samples which are extremely quartz rich with rock fragments also increasing in adundance. Casings were put in at 436m and 1301m.

2.6.2 Well 6406/11-1

The general lithology of Well 6406/11-1 is shown in Fig. 7. From the base of the section studied (2350m) to approximately 1235m the lithology consists of consolidated claystones, siltstones and shales with traces of mica, pyrite and sand. Traces of glauconite are also noted towards the top of this section at around 1500m. From 1857m to 1887m the Brygge Sand is recorded. Above 1235m the lithology changes to generally unconsolidated fine to medium grained and medium to poorly sorted sands. Rock and shell fragments are also present. This change occurs at the same level as a dramatic increase in the sand fraction. Casings were placed in the well at 449m, 1201m and 2151m.

Group/Formation	Lithology	Lateral Extent and Variation	Age	Depositional Environment
Nordland Group	Alternating claystone, siltstone and sandstone	Present throughout the Mid-Norwegian shelf, the lower part is not present on the crest of the Nordland Ridge	Early Miocene to Recent	Marine environment in a rapidly subsiding basin charecterised by major westerly prograding wedges. The upper part is of glacial to glacio-marine origin
• Naust Formation	Interbedded claystone, siltstone and sand, occasionally with very coarse clastics in the upper part	Laterally continuous across the Mid-Norwegian shelf	Late Pliocene	Marine environment
• Kai Formation	Alternating claystone, siltstone and sandstone with limestone stringers. Glauconite, pyrite and shell fragments are common	Present throughout the Haltenbanken area apart from the crest of the Nordland Ridge. The sand content varies locally	Early Miocene to L. Pliocene	Marine environments with varying water depths
Hordaland Group	Claystones and minor sandstones, herein assigned to the Brygge formation. The sandstone content increases to the east	Occurs throughout Haltenbanken. Thins eastwards and is eroded on the Nordland Ridge. Close to the coastline the group comprises a sandy sequence	Eocene to Early Miocene	Marine environments
• Brygge Formation	Mainly claystone with stringers of sandstone, siltstone, limestone and marl. Pyrite, glauconite and shell fragments are seen in the sandstones	Ubiquitous across Haltenbanken, but absent on the crest of the Nordland Ridge	Early Eocene to Late Miocene	Marine environments
Rogaland Group	Claystone with minor local siltstone. Tuff is common in the upper part	The lower part of the group is not present in the northeastern part of the Haltenbanken area. The upper tuffaceous part is ubiquitous, except for the crest of the Nordland Ridge. Tuff content	Danian to Late Paleocene	Deep marine environment
• Tare Formation	Dark grey, green or brown claystones with some thin sandstone stringers show a variable content of tuff	Ubiquitous except near the crest of the Nordland Ridge. The tuff content decreases southwards	Late Paleocene	Deep marine environment
• Tang Formation	Dark grey to brown claystone with minor sandstone and limestone	Thins towards the northeast. It is not present on the Nordland Ridge	Danian to Late Paleocene	Deep marine environment
• Lista Formation	brown-grey to brown shales, generally non tuffaceous & poorly laminated. Occasional stringers of Limestone, dolomite and pyrite. Thin sandstone layers locally	Widespread in the Norwegian North Sea	Late Paleocene	Relatively deep water, low energy environments
• Sele Formation	Tuffaceous montmerillonite rich shale, grey-greenish grey. Finely laminated and carbonaceous. Minor interbeds of laminated sandstone, frequently glauconitic	Widely distributed throughout the North Sea	Late Paleocene	Deep marine setting, similar to that of the Lista Formation

Table 2. Description of lithologies on the mid-Norwegian Shelf.
Data from Dalland *et al.* (1988)
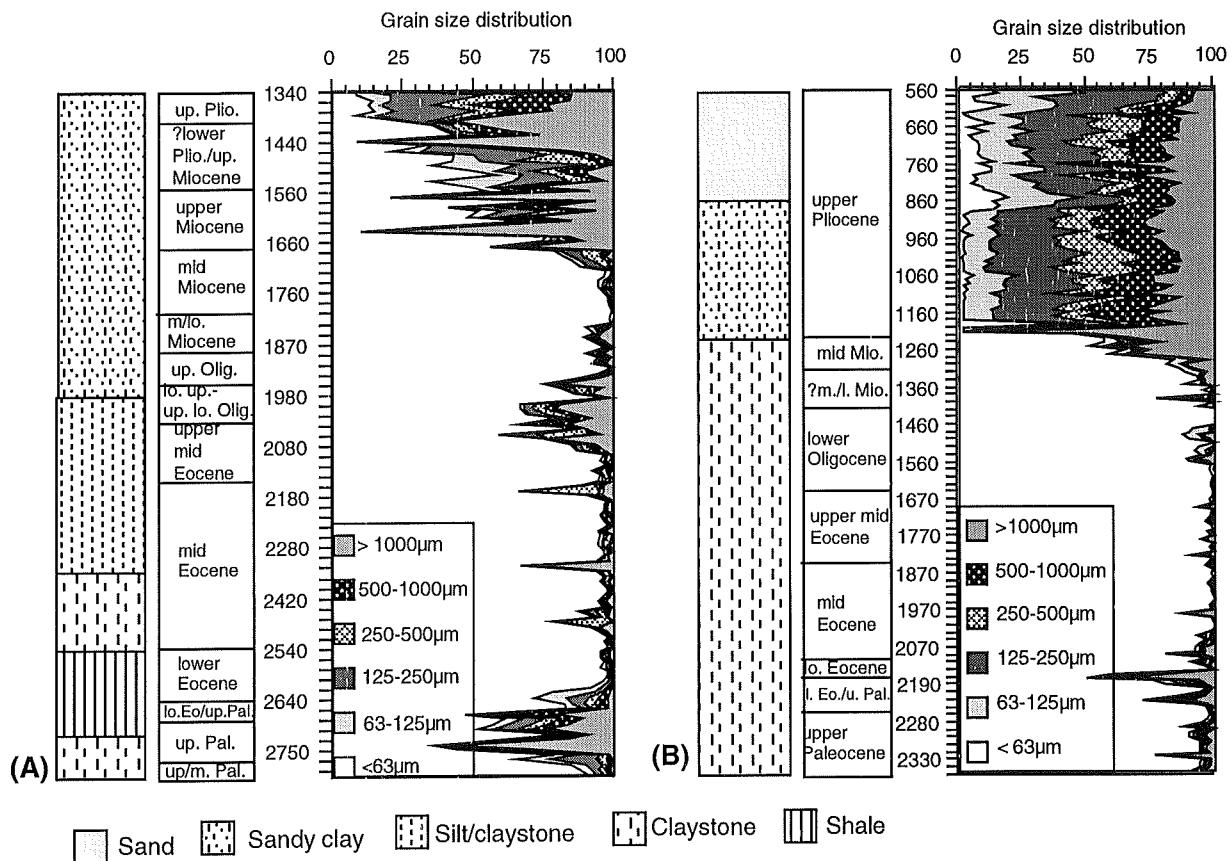
Figure 7. General lithology and grain size analysis for (A) Well 6406/8-1 and (B) 6406/11-1

2.6.3 Well 6407/7-2

Fig. 8 shows the general lithology of Well 6407/7-2. Again the lithology can be split into two main units. From 2000m up to approximately 1030m the lithology consists of claystones with occasional limestone and sand stringers. One area of note is between 1047m to 1078m where high quantities of glauconite are observed. A similar unit can be seen in well 6407/9-3. Above this the lithology becomes richer in quartz and consists of medium to very sandy claystones. Rock fragments are also recorded above 1040m. Casings were placed at 445m, 757m and 1502m.

2.6.4 Well 6407/9-3

Fig. 8 depicts the lithology from Well 6407/9-3. As in the other three wells the lithology can be split into two main units. From 1540m to 700m the lithology consists of claystones and siltstones. At the top of this unit from 750m to 840m there is an interval extremely rich in glauconite similar to that seen in Well 6407/7-2. Above this to 390m there are sandy silts with shell fragments and traces of pyrite. As in the other wells the sand fraction and rock fragments increase in abundance above 750m. Casings were placed at 376.5m, 769m, and 1601m.

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Figure 8. General lithology and grain size distribution for (A) Well 6407/7-2 and (B) Well 6407/9-3

3. Methods

3.1 Laboratory techniques

The analyses were carried out on cutting samples. In using cutting samples there is the great danger of down-hole contamination through 'caving' i.e. microfossils from stratigraphically younger strata falling down-hole, destruction of delicate taxa and size sorting. For a full account of the problems inherent in using such material s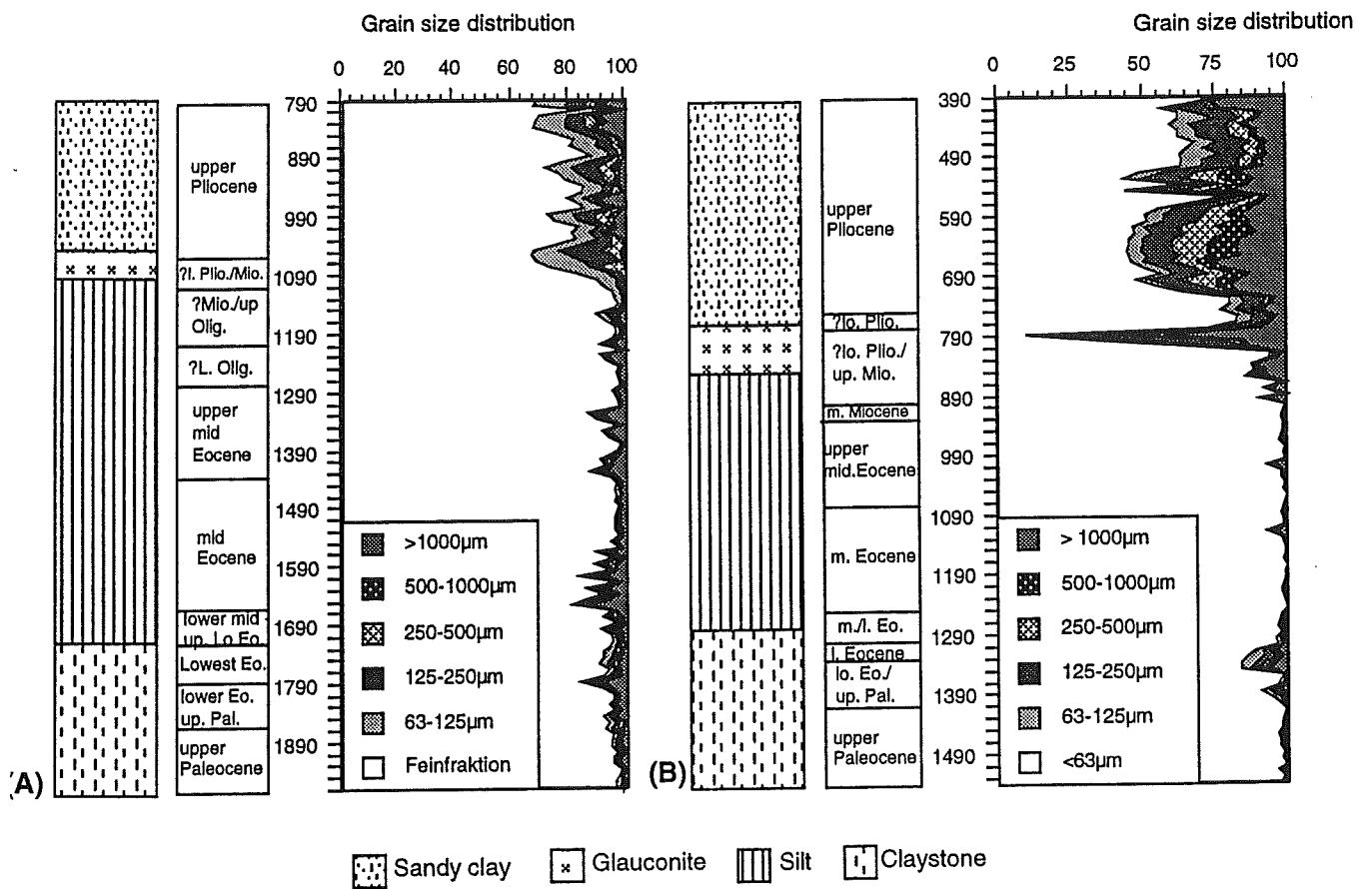ee King (1983). Therefore, the most reliable method for constructing a biostratigraphic time scale or zonation scheme is by recording the last observed occurrences (or first down-hole occurrences) of species, using relative abundances of taxa and acme occurrences as these are less affected by such problems and more likely to be *in situ*. Obviously out of place foraminifers can be recognised by a variety of means e.g. different modes and degrees of preservation to the predominant fauna and obviously out of place forms such as Pliocene planktic foraminifers and calcareous benthic foraminifers in the predominantly agglutinated sections of the Paleocene and Eocene. Quantitative techniques can be used on cutting samples bearing in mind that care must be taken to try and distinguish those species present due to down-hole contamination and reworking as these can seriously skew any results obtained.

The wells were studied roughly every 10-20m. The samples usually started at about 100-300 m below the sea floor. Above this, sample material was not collected but returned straight to the sea bed. Therefore, the Quaternary is not represented in the samples studied.

Since the amount of sample received for each well varied widely, from 5g - 50g, and from each sample a micropalaeontological, sedimentological and archive split needed to be taken, it was not possible to take the same amount of sample from each well or depth. Where enough material was available, a subsample of around 20g or greater was taken for micropalaeontological purposes. In Well 6406/8-1 much less material was available and therefore the samples were often 10g or less.

The samples were first soaked in distilled water for 24hrs, freeze-dried and then weighed to obtain the total dry weight of sediment. Due to the presence of high amounts of clay in the lower samples which proved extremely difficult to get rid of, a number of further preparation methods were tested to disaggregate the clay. These methods include:

1. Boiling with a 1% mixture of 'Calgon', wet sieving and drying: This method was fairly successful for those samples which only had a medium amount of clay or which were not too consolidated. With other samples however, it failed to get rid of all the clay and aggregates of clay particles were still to be found in the dried samples.

2. Boiling in paraffin and potassium hydroxide (KOH): This method was also partially successful the major drawback being that it was very time consuming. Each sample first had to be boiled with paraffin until no air bubbles were seen which could often take up to one hour. The paraffin then had to be poured off and once the sample was cool potassium hydroxide added and the sample again boiled for about a further hour. Once cool the sample was wet sieved and dried.
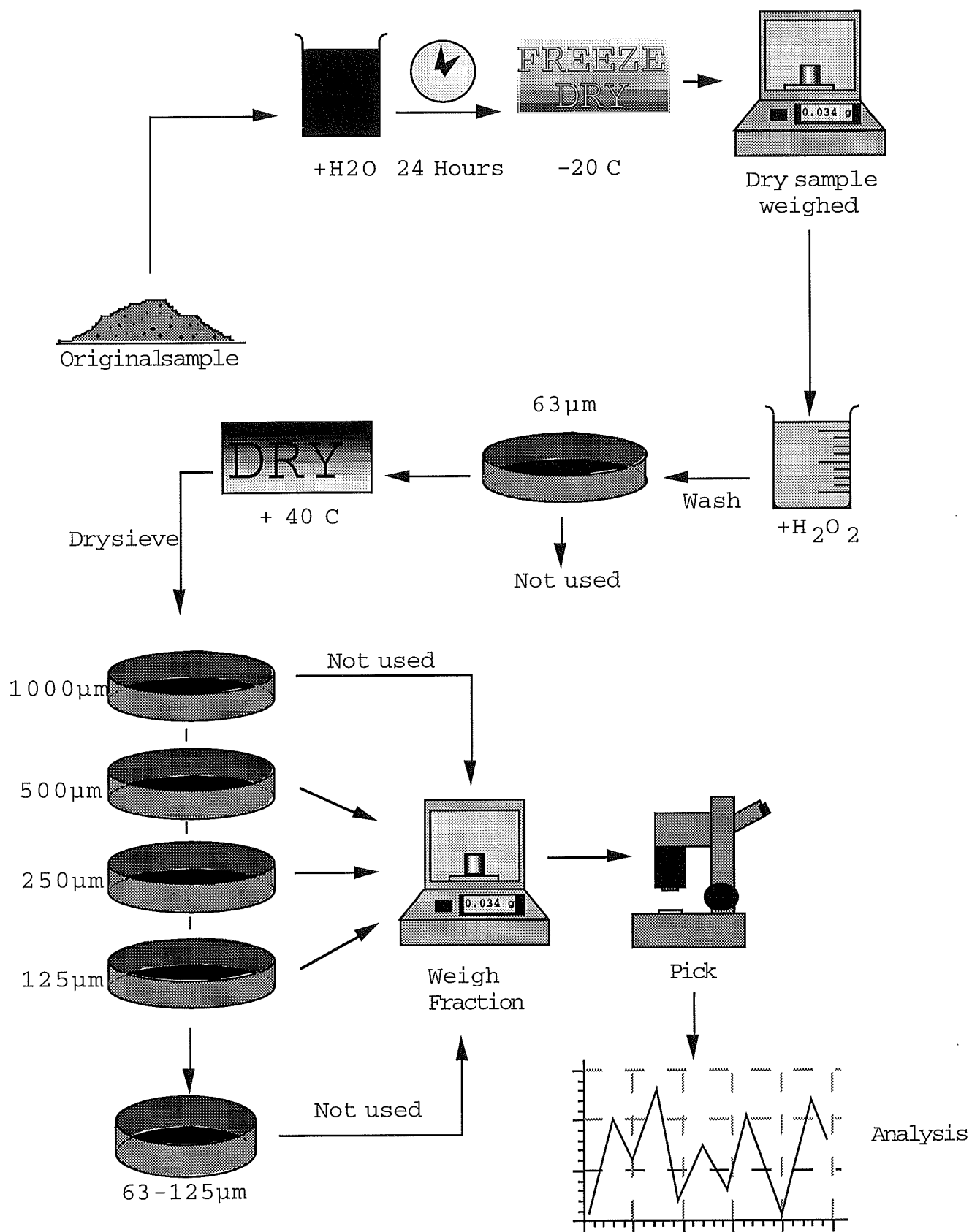
Figure 9. Preparation methods used for micropalaeontological analysis.

3. Adding tenside to the samples and washing through with hot/warm water. Although relatively quick and easy this again was only partially successful in getting rid of the clay.

The most successful method in terms of both time and efficiency and the one that was finally adopted was to first soak the samples in dilute hydrogen peroxide (1 part 35% H_2O_2, to 4 parts water) for a maximum of 24hrs, wet sieve through a 63μm and then dry at 40°C (Fig. 9) although even with this method some clay aggregates remained. However, with ever harsher methods of preparation, there was also the risk that some foraminifers would also be destroyed, so it was felt that some compromise had to be made between efficiency of clay removal and preservation of microfossils.

The dried samples were then sieved into the fractions 63-125μm, 125-250μm, 250-500μm, 500-1000μm and > 1000μm and weighed. For the micropalaeontological investigations the fractions 125-250μm, 250-500μm and 500-1000μm were used. Using a binocular microscope foraminifers were picked from each depth and mounted on faunal slides. Wherever possible at least 300 foraminifers were picked. Other microfossils such as ostracods, diatoms, radiolarians, bolboforma and fish teeth were also picked and/or counted.

3.2 Palaeoenvironmental analysis

To obtain information about changes in palaeoceanography from the Paleocene to the Pliocene several different parameters were investigated. These include: species frequency and abundance, the relative proportions of calcareous and agglutinated foraminifers, other microfossil groups, infaunal and epifaunal foraminifers and foraminiferal morphogroups. The Shannon-Weaver information function was also used.

A useful indicator of (palaeo) environmental conditions is the relative abundance and diversity of assemblages. In more stressed environments where high competitivity is not necessary and where many ecological niches may remain practically unfilled there is often a dominance by a few opportunistic species or r-selected species. These species generally have a high reproduction rate and are able to take advantage of any sudden influx of nutrients to the sea floor. In more favourable environments there is a wide spread of niches filled by a wide variety of K-selected species which are highly specialised and tend to live in one kind of environment only (Sjoerdsma and van der Zwaan, 1992).

3.2.1 Shannon-Weaver Index

The Shannon-Weaver information function H(S) as proposed by Shannon and Weaver (1949) is a measure of heterogeneity which takes into account the number of species and the distribution of individuals between species (Murray, 1991). This is often used as an index of diversity.

It is calculated:

$$H(S) = -\sum_{i=1}^{S} p_i \ln p_i$$

where S is the number of species and p_i the proportion of the ith species (p = per cent divided by 100).

3.2.2. Morphogroup analysis

For the purpose of identifying palaeoenvironments, morphogroups for the agglutinated and calcareous foraminifers were devised and analysed. Morphogroups are formed by grouping together foraminifers of similar morphologies e.g elongated, planoconvex. Changes in the relative proportions of different morphogroups can act as an indicator of differing palaeoenvironments. A full explanation and results are given in chapter 5.

4. Biostratigraphy

4.1 Introduction

Several attempts have been made to produce a foraminiferal zonal scheme for the area of the Norwegian Sea and to link these to schemes in related areas such as the North Sea, Labrador Sea and Northern Atlantic. The main problems encountered when trying to correlate schemes from the Norwegian Sea to other areas is that for much of its history the Norwegian-Greenland Sea has been an isolated basin with hydrographic properties often very different from those of the main North Atlantic. This, coupled with its high latitude position, has led to relatively low diversity foraminiferal assemblages, often comprised of slowly evolving, endemic species which cannot be easily compared to other coeval assemblages from the related areas of the North Sea or Labrador Sea. However, such studies have proved of use in deducing and unravelling the palaeoceanographic and tectonic history of the Norwegian Greenland Sea and are especially useful in determining the histories of the submergence of the Greenland-Scotland (Iceland-Faroe) Ridge and of the connection to the Arctic Ocean through the opening of the Fram Strait.

An overview of each of the wells studied here is presented and assemblages defined. A biostratigraphical scheme for the Halten Terrace is proposed based on the findings from this work and then the wells are correlated with one another. The main studies to date are summarised and discussed and correlations are made with other biostratigraphies.

4.2 Assemblages

The assemblages for the four wells in this study were defined by using first downhole occurrences and acme occurrences of benthic foraminifers - both agglutinated and calcareous. Where no age diagnostic foraminifers were recorded or other microfossils were more prominant or better suited for biostratigraphic purposes, radiolarians, diatoms, bolboforms and planktic foraminifera were utilised. Within each well the last observed occurrence (last occurrence or LO) and last common occurrence (LCO) of microfossils is noted. All depths quoted are depth below kelly bushing. In each case this means subtracting around 27m from each depth to obtain the true depth below sea level.

4.2.1 Well 6406/8-1 (Fig. 10)

Position N: 64°21'55.01"
Position E: 06°26'48.16"
Water depth 348m

***Trochammina ruthven-murrayi* Assemblage**
Interval: 2800m-2780m

SERIES	Depth (m)	EVENTS	ASSEMBLAGES
upper Pliocene	1400	◄⌐M. barleeanum	Impoverished
			Melonis barleeanum
			Cassidulina teretis
?lower Pliocene/ upper Miocene	1500		Impoverished/barren
		◄—Bolboforma metzmacheri	
?upper Miocene	1600		Bolboforma metzmacheri
	1700	◄⌐Martinottiella communis	
mid Miocene			Martinottiella communis
?mid/lower Miocene	1800	◄ ⌐ Neogene Rad. flood ◄⌐	Barren/ Siliceous
upper Oligocene	1900	◄⌐tubular forms Ammodiscus tenuissimus	coarse agglutinated foraminifers
lower up.- upper lo. Oligocene	2000	◄⌐Cyclammina placenta S. compressa ◄⌐Ammodiscus pennyi ◄—Coscinodiscus sp. 3	Spirosigmoilinella compressa
		◄⌐G. charoides	
upper mid Eocene	2100	◄⌐S. compressa ◄⌐Karrerulina conversa ◄⌐Ammomarginulina aubertae ◄⌐S. spectabilis	Glomospira charoides
	2200	◄⌐R. amplectens ◄⌐Adercotryma agterbergi ◄⌐Haplophragmoides kirki	Reticulophragmium amplectens
mid Eocene	2300		
	2400	◄⌐Karrerulina horrida	
	2500	◄⌐S. navarroana	
lower Eocene		◄⌐Glomospira gordialis	Karrerulina conversa Spiroplectammina navarroana
	2600		
		◄—Coscinodiscus spp.	
lo.Eocene/ up. Pal.			Impoverished
upper Paleocene	2700	◄⌐LCO S. spectabilis ◄⌐Rzehakina minima	Spiroplectammina spectabilis
up/?m. Pal	2800	◄⌐T. ruthven-murrayi	Trochammina ruthven-murrayi

◄⌐ Last occurrence
◄⌐ First occurrence

Figure 10. Assemblages and LOs for Well 6406/8-1

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Age: late/mid Paleocene
Lithostratigraphic unit: Tang Formation
Foraminifers /g: 32-52
Species/sample: 28-30

An abundant and diverse assemblage of agglutinated benthic foraminifers with many typical 'flysch type' foraminifers e.g. ammodiscids, tubular forms, trochamminids etc. Most of the foraminifers are finely grained, finely finished and well preserved. In colour they are generally white or brown along with some green tubes. Tubular forms dominate numerically. Siliceous microfossils are unimportant. The planktic foraminifers *Hedbergella* sp. and *Heterohelix* sp. are also observed in this assemblage at 2800m, although these may be reworked as they are badly preserved.
LO: *Trochammina ruthven-murrayi, Hormosina ovulum, Dorothia* sp.,

Spiroplectammina spectabilis Assemblage
Interval: 2760m-2690m
Age: late Paleocene
Lithostratigraphic unit: Tang Formation
Foraminifers /g: 14-51
Species/sample: 17-28

Apart from the ubiquitous tubular forms the assemblage is dominated by the nominate taxa. Also important are *Saccammina placenta*, ammodiscids and trochamminids, i.e. again typical 'flysch type' faunas. Many of the foraminifers have a greenish or brownish tinge. Pyritized diatoms are also seen.
LCO: *S. spectabilis*
LO: *Kalamopsis grzybowskii, Rzehakina epigona, Reophax duplex, Recurvoides* ex. gr. *gerochi.*

Impoverished interval
Interval: 2680m-2650m
Age: ?earliest Eocene/late Paleocene
Lithostratigraphic unit: Tare Formation
Foraminifers /g: 1-4
Species/sample: 3-7

Very few foraminifers are recorded within this zone. A few radiolarians and diatoms are present.
LO: None

Karrerulina conversa - Spiroplectammina navarroana Assemblage
Interval: 2640m-2540m
Age: early Eocene

Lithostratigraphic unit: Brygge Formation

Foraminifers /g: 15-95

Species/sample: 14-29

A return to an abundant and diverse assemblage. *Karrerulina conversa, K. horrida* and *Spiroplectammina navarroana* all have peak occurrences within this assemblage. Tubular forms again dominate and the foraminifers within this assemblage are very similar to those in the *Trochammina ruthven-murrayi* Assemblage. Up to 2500m many of the foraminifers are again coloured green or brown after which they are generally white to cream in colour.

At the bottom of this assemblage large numbers of the diatoms *Coscinodiscus* spp. are found. LO: *Glomospira gordialis, G. diffundens, Cystammina pauciloculata, Lituotuba lituiformis, S. navarroana, Recurvoides* sp. 3

Reticulophragmium amplectens Assemblage

Interval: 2520m-2160m

Age: mid Eocene

Lithostratigraphic unit: Kai Formation

Foraminifers /g: 17-138

Species/sample: 12-25

The assemblage initially displays high abundance and diversity, however towards the top of the interval a decrease and a large number of LOs is observed. The foraminifers are again similar to those in the previous assemblages with an increase in the number of the nominate taxon, and an increase in the numbers of *Cribrostomoides* spp. and *Recurvoides* spp. Unfortunately most of these are long ranging and therefore of limited use for stratigraphical purposes. *Bigenerina* sp. 1 (Charnock and Jones, 1990) and *Ammolagena clavata* are only seen within this assemblage. *Reticulophragmium amplectens* does range into the previous assemblage but has its acme occurrence here. Unlike in the other three observed wells, *R. amplectens* does not become as or more abundant than the tubular forms. Towards the top of the assemblage siliceous microfossils increase in abundance.

LO: *Karrerulina horrida, Ammodiscus cretaceus, Ammosphaeroidina pseudopauciloculata, Haplophragmoides stomatus, H.* cf. *kirki* (coarse), *Bigenerina* sp., *Evolutina* sp., *Cyclammina rotundidorsata, Saccammina grzybowskii, Karrerulina chapapotensis, Spiroplectammina derperdita, Trochammina* sp. 2, *Reticulophragmoides jarvisi. Haplophragmoides horridus, H. walteri excavatus, H. kirki, H.* cf. *concavus, Adercotryma agterbergi, Trochammina globigeriniformis, T. altiformis, Trochammina* sp. 3 (Charnock and Jones, 1990), *Trochammina* sp. 1 (Charnock and Jones, 1990), *Glomospira serpens, G. irregularis, G. glomerata, Trochamminoides* spp., *Haplophragmoides?/ Cribrostomoides, R. amplectens.*

Glomospira charoides **Assemblage**

Interval: 2140m-2040m

Age: late mid Eocene

Lithostratigraphic unit: Kai Formation

Foraminifers /g: 11-40

Species/sample: 7-14

Low diversities are observed throughout this interval. *Recurvoides* spp. and *Cribrostomoides* spp. are again numerically important together with tubular forms. *Haplophragmoides walteri* is also present. Radiolarians are abundant and account for approximately 50% of total biogenic components.

LO: *Haplophragmoides porrectus, Spiroplectammina spectabilis, Subreophax scalaris, Ammomarginulina aubertae, Karrerulina conversa, Ammodiscus* sp., *Glomospira charoides, Reophax* sp., *Hyperammina/Hormosina* fragments.

Spirosigmoilinella compressa **Assemblage**

Interval: 2020m-1960m

Age: early late Oligocene to late early Oligocene

Lithostratigraphic unit: Kai Formation

Foraminifers/g: 7-15

Species/sample: 7-13

The assemblage includes the LO of *S. compressa*. Diversity and abundance are generally low. Siliceous fossils are the dominant microfossils, radiolarians account for about 20% of the total assemblage and diatoms also increase in importance having a peak at the top of the assemblage of about 8%. A large number of pyritized burrows or worm tubes are also recorded. At 2020m Diatom sp. 3 (King) is observed which has a range from the upper Lower Oligocene to Lower Miocene.

LO: *Trochammina* spp., *Haplophragmoides walteri, H. suborbicularis Spirosigmoilinella compressa, Ammodiscus pennyi, Saccammina placenta, Cyclammina placenta.*

Coarse agglutinated foraminifers Assemblage

Interval: 1940m-1880m

Age: late Oligocene

Lithostratigraphic unit: Kai Formation

Foraminifers /g: 1-7

Species/sample: 1-4

Very low abundances and diversities. Agglutinated foraminifers disappear within this assemblage with tubular forms the last to disappear at 1900m.

Siliceous forms are again dominant, although low in actual numbers.

LO: tubular forms, *Ammodiscus tenuissimus, Glomospira* spp., *?Recurvoides/ Cribrostomoides* spp.

Barren interval with siliceous microfossils

Interval: 1860m-1800m

Age: ?mid/early Miocene

Lithostratigraphic unit: Kai Formation

Foraminifers /g: 0

Species/sample: 0

Barren of foraminifers and dominated by siliceous microfossils especially radiolarians. This may represent the 'Neogene Radiolarian Flood' of Gradstein *et al.,* (1988), which would place this assemblage in the lower mid Miocene.

LO: none

Martinottiella communis **Assemblage**

Interval: 1780m-1680m

Age: mid Miocene

Lithostratigraphic unit: Kai/Naust Formation

Foraminifers /g: 0-3

Species/sample: 0-2

Generally barren of foraminifers except for the occurrence of *Martinottiella communis.*

At the base of the interval radiolarians represent up to 80% of the total biogenic assemblage, they then decrease to 40% near the top. Diatoms increase in abundance throughout the assemblage and at the top make up 11% of the total assemblage. Sponge spicules show a small peak of around 10% at 1720m. The zone NSR9B described by Gradstein and Bäckström (1996) is similar to this assemblage and was given an age of upper Mid to lower Upper Miocene.

LO: *Martinottiella communis.*

Bolboforma metzmacheri **(bolboforma)**

Interval: 1660m-1560m

Age: ?late Miocene

Lithostratigraphic unit: Naust Formation

Foraminifers /g: 0-5 (1560-19.76)

Species/sample: 0-4 (1560-16)

The base of the assemblage is marked by a semi-barren interval from 1660m-1580m. At 1560m calcareous faunas such as *Cassidulina teretis, Cibicides* spp., *Melonis barleeanum* and *Elphidium* spp. are observed, as well as the Upper Miocene *Bolboforma metzmacheri* . However due to the very low numbers seen and the relatively bad preservation it is hard to state definitely that the microfossils found here are *in situ* and they could well be the result of caving and/or reworking. Both radiolarians and sponge spicules are abundant within the assemblage.

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LO: *Cibicidoides pachyderma, Cibicides refulgens, C. sulzensis, Glandulina* sp., *Procerolagena gracillima.*

Impoverished/barren interval

Interval: 1540m-1400m

Age: ?early Pliocene/late Miocene

Lithostratigraphic unit: Naust Formation

Foraminifers /g: 0-4

Species/sample: 0-2

A semi-barren interval with only a few calcareous benthics observed. Siliceous microfossils are also rare.

LO: None

Melonis barleeanum - Cassidulina teretis Assemblage

Interval: 1390m-1380m

Age: late Pliocene

Lithostratigraphic unit: Naust Formation

Foraminifers /g: 6-26

Species/sample: 10-28

The base of the assemblage is marked by the occurrence of high numbers of the above species from 1390m to 1380m. *Quinqueloculina seminulum, Elphidium* spp., *Trifarina* spp. and buliminids also appear for the first time in this assemblage. Although *Cibicides grossus* is seen throughout this assemblage it is only present in very low numbers.

LO: *Cibicides* sp., *Nodosaria* sp., *Trifarina angulosa, T. fluens, Bulimina gibba, Stainforthia loeblichi, Elphidium excavatum* f. *clavata, E. macellum, E. subarcticum, Melonis barleeanum, Cassidulina obtusa, C. reniforme, Globocassidulina subglobosa, Islandiella helanae.*

Impoverished interval

Interval: 1370-1340

Age: late Pliocene

Lithostratigraphic unit: Naust Formation

Foraminifers /g: 1-4

Species/sample: 4-9

There is a distinct decrease in abundance and diversity within this sequence. The small influx of *Fissurina* spp. and *Oolina* spp. observed in the other wells is not seen here and the number of buliminids remains low.

Many of the species which show an LO in this assemblage are still extant. Therefore their last occurrences are only local.

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4.2.2 Well 6406/11-1 (Fig. 11)

Position N: 64°02'46.22"

Position E: 06°36'14.16"

Water depth: 315m

Trochammina ruthven-murrayi - Spiroplectammina spectabilis Assemblage

Interval: 2350m-2250m

Age: late Paleocene

Lithostratigraphic unit: Tang Formation

Foraminifers/g: 8-29

Species/sample: 23-40

Diverse and abundant assemblage with well preserved foraminifers often with a brownish (to 2310m) or greenish (to 2270m) colour. In general, the foraminifers have a finely grained and finely finished wall. Tubular forms are numerically dominant and tend to be relatively thick and rounded in cross-section and belong mainly to the genera *Bathysiphon* and *Rhabdammina*. Other important foraminifers include *Haplophragmoides walteri, Saccammina placenta,* and *Ammosphaeroidina pseudopauciloculata. Karrerulina conversa* and some ammodiscids have acme occurrences within this assemblage and the LCO of *S. spectabilis* is also recorded. A number of *Trochamminoides* spp. are also found. Siliceous faunas are present but not important.

LO: *Paratrochamminoides* sp., *Trochammina ruthven-murrayi, Hormosina ovulum, Kalamopsis grzybowskii, Haplophragmoides suborbicularis, Haplophragmoides* sp. 2., *Trochammina subvesicularis, Trochammina* sp. 4. (Charnock and Jones, 1990), *Trochammina* sp. 1. (Charnock and Jones, 1990), *Trochammina* sp. 3. (Charnock and Jones, 1990), *Pseudobolivina* sp., *Hormosina* sp., *Verneuilinulla* sp., *Rzehakina minima, Glomospira irregularis, Reophax* sp. 2 (Kuhnt 1990), *Hormosina excelsa, Trochamminoides irregularis.*

LCO: *S. spectabilis.*

Barren interval

Interval: 2240m-2160m

Age: ?early Eocene/late Paleocene

Lithostratigraphic unit: Tang and Tare Formations

Foraminifers/g: 0

Species/sample: 0

Barren of foraminifers. Other microfossils e.g. diatoms, radiolarians etc. are present only in very low numbers.

LO: None

Figure 11 — Assemblages and LOs for Well 6406/11-1

SERIES	Depth (m)	EVENTS	ASSEMBLAGES
upper Pliocene	600		
	700		*Elphidium excavatum f. clavata* / *Cassidulina teretis* / *Cibicides grossus*
	800		
	900		
	1000		*Cassidulina teretis- Cibicides grossus- Melonis barleeanum*
	1100		
	1200		
mid Miocene		◀ *Bolbo.* cf. *badenensis* / *B. compressi* gp / ◀ *B. voeringensis* / ◀ Calcareous faunas	*Cassidulina teretis - Melonis Barleeanum Bolboforma* spp.
	1300		
?mid/lower Miocene		◀ Neogene Rad. flood	Impoverished / *Uvigerina tenuipustulata Melonis barleeanum*
	1400	◀ *T. alsatica*	*Turrilina alsatica*
lower Oligocene	1500		Impoverished/siliceous
		◀ tubular forms	
	1600	◀ *Rotaliatina bulimoides* / ◀ Agglutinated species / *Karrerulina horrida* / *Ammodiscus tenuissimus*	Coarse agglutinated forms
upper mid Eocene	1700	◀ *S. spectabilis*	*Glomospira charoides*
	1800	◀ *G. charoides*	
		◀ *R. amplectens*	
	1900		
mid Eocene	2000	◀ Eocene Rad. flood / ◀ *Karrerulina conversa* / ◀ *Spirop. navarroana*	*Reticulophragmium amplectens*
		◀ *Haplophragmoides kirki*	
		◀ *Ammodiscus pennyi*	
lower Eocene	2100	◀ *Glomospira diffundens* / *G. gordialis*	*Karrerulina* spp.
lower Eo./ upper Paleocene	2200		Barren
		◀ *Rzehakina minima* / ◀ LCO *S. spectabilis* / ◀ *T. ruthven-murrayi*	*Trochammina ruthven-murrayi*
upper Paleocene	2300		*Spiroplectammina spectabilis*

◀ Last occurrence
◀ First occurrence

Figure 11. Assemblages and LOs for Well 6406/11-1

Karrerulina spp. Assemblage

Interval: 2150m-2100m

Age: early Eocene

Lithostratigraphic unit: Brygge Formation

Foraminifers/g: 4-10

Species/sample: 16-27

A return to a diverse assemblage with many of the foraminifers found in the *T. ruthven-murrayi - S. spectabilis* Assemblage. However, there is a distinct decrease in the numbers of ammodiscids. The foraminifers also differ in their whitish/cream colour. The assemblage is characterised by a maximum in the number of *Karrerulina horrida. Karrerulina conversa* and *Recurvoides* spp. are also important. he planktic species *Subbotina patagonica* was not recorded in this well. Siliceous forms especially radiolarians begin to become an important part of the total fauna representing over 40% of the total assemblage.

LO: *Ammodiscus peruvianus, Glomospira diffundens, G. gordialis, Haplophragmoides* cf. *concavus, Trochamminoides subcoronatus.*

Reticulophragmium amplectens Assemblage

Interval: 2080m-1860m

Age: mid Eocene

Lithostratigraphic unit: Brygge Formation

Foraminifers/g: 1-8

Species/sample: 23-3

An *R. amplectens* acme occurs at around 2060-1960m. Within this assemblage tubular forms e.g. *Bathysiphon* and *Rhabdammina* become less important and disappear by 2000m. This corresponds to the increase in *R. amplectens.* Above this interval tubular forms gradually start to increase in numbers once again. Above 2000m the foraminifers start to become coarser grained. In general the assemblage is characterised by a decrease in diversity from around 20 species/sample at the bottom of the assemblage to only ca. 3 species/sample at the top of the assemblage. There is also a large increase in the abundance of siliceous microfossils especially radiolarians, particularly between 1980-1940m (>90%). This peak may correspond to the Eocene radiolarian flood found by Gradstein *et al.* (1988) during the lower Mid Eocene. At the top of the assemblage radiolarians make up almost 100% of the total biogenic components.

LO: *Ammodiscus pennyi, A. cretaceus, Haplophragmoides kirki, H. walteri excavatus, H. porrectus, H. stomatus, Subreophax scalaris, Hyperammina/Hormosina* fragments, *Cystammina pauciloculata, Subreophax guttifer, Spiroplectammina navarroana, Karrerulina conversa, Ammosphaeroidina pseudopauciloculata, Trochammina altiformis, Saccammina placenta, Lituotuba lituiformis, R. amplectens.*

Glomospira charoides **Assemblage**

Interval: 1840m-1640m

Age: late mid Eocene

Lithostratigraphic unit: Brygge Formation

Foraminifers/g: 0-3

Species/sample: 0-10

Very much less diverse and abundant than the previous assemblages. Tubular forms again dominate, but are less robust than before and show more twisted segments, e.g. more typical *Rhizammina* type tubular forms. The foraminifers in general are much coarser grained. A small peak in the abundance of *Glomospira charoides* occurs between 1780m-1820m. This event may be correlatable across the 4 wells studied. Radiolaria are still important, representing around 50% of all biogenic components, and diatoms become increasingly important showing peaks of abundance at 1800m and 1900m and having an abundance of over 80% between 1600m-1620m. The LO of *Spiroplectammina spectabilis* occurs in the Lower to upper Mid Eocene (Gradstein and Bäckström, 1996)

LO: *Glomospira charoides, Trochammina* sp. (coarse), *Reophax* sp., *Trochamminoides* sp., *Eggerella bradyi, Spiroplectammina spectabilis, Haplophragmoides walteri.*

Coarse agglutinated foraminifers

Interval: 1620m-1540m

Age: early Oligocene

Lithostratigraphic unit: Brygge Formation

Foraminifers/g: 1-2

Species/sample: 1-14

Extremely low diversity and abundance assemblage dominated by coarse agglutinated tubes. Most agglutinated foraminifers have their last appearance at 1600m except for the tubular forms which disappear at 1540m. This loss of agglutinated species around the Eocene/Oligocene boundary is also recorded in the Southern Labrador Sea, Viking Graben, Beaufort Sea and shallow DSDP Site 338, but not in the deep Norwegian Sea where agglutinated forms are found up into the Miocene. The LOs of *Karrerulina horrida* and *Rotaliatina bulimoides* occur during the Lower Oligocene.

LO: *Ammodiscus tenuissimus, Karrerulina horrida, H. horrida, Haplophragmoides* sp., *Recurvoides* ex. gr. *turbinatus, Rotaliatina bulimoides, Cibicides akneriensis, Quinqueloculina stalkeri, Lagena* cf. *appiopleura, Procerolagena gracillima,* tubular forms.

Impoverished/siliceous assemblage

Interval: 1520m-1500m

Age: early Oligocene

Lithostratigraphic unit: Brygge Formation

Foraminifers/g: 1-2

Species/sample: 1-7

Again a near barren assemblage, often with only 2-3 species/sample. The first appearance of badly preserved calcareous foraminifers occurs within this assemblage, however many of these specimens are probably caved as several are typical Pliocene forms. Siliceous microfossils are again dominant with radiolarians being the most important element within this assemblage (around 40-50%). Diatoms begin to decrease in importance and sponge spicules increase in importance (ca. 30%)
LO: None.

Turrilina alsatica Assemblage

Interval: 1480m-1400m
Age: early Oligocene
Lithostratigraphic unit: Brygge Formation
Foraminifers/g: 0-2
Species/sample: 0-9

The Lower Oligocene marker *Turrilina alsatica* is found at 1420m and 1480m, otherwise the assemblage is very impoverished. Kaiho (1991) has stated that *T. alsatica* indicates low to intermediate oxygenation of bottom waters. Siliceous microfossils are again dominant, with radiolarians and sponge spicules being most important.
LO: *Turrilina alsatica, Triloculina trihedra, Eggerella parkerae.*

Impoverished/*Uvigerina tenuipustulata - Melonis barleeanum.* Assemblage

Interval: 1380m-1310m
Age: ?mid/early Miocene
Lithostratigraphic unit: Kai Formation
Foraminifers/g: 0-3
Species/sample: 0-9

The assemblage is near barren. At 1370-1350m there is a sudden influx of *Uvigerina tenuipustulata* and *Melonis barleeanum.* At 1380m there is a radiolarian flood where radiolarians make up more than 90% of the total microfossil content. This may be equivalent to the Neogene radiolarian flood placed in the lower Mid Miocene by Gradstein *et al.,* (1988).
LO: *Pullenia quinqueloba, Uvigerina tenuipustulata, Nonion auricula.*

Cassidulina teretis - Melonis barleeanum plus *Bolboforma* spp. Assemblage

Interval: 1290m-1220m
Age: mid Miocene
Lithostratigraphic unit: Kai Formation
Foraminifers/g: 1-18
Species/sample: 5-37

This assemblage contains the first well preserved calcareous foraminifers, including the nominate taxa and species of *Cibicides*, *Elphidium* and *Bulimina*. Diversity increases throughout the assemblage and siliceous fossils decrease rapidly in abundance. Above 1235m they are rare or absent. Miocene bolboforms are also observed within this assemblage and from 1210m shell fragments, ostracods and echinoid spines are also seen. The LO of *Ehrenbergina variabilis* occurs during the upper mid to lower Upper Miocene.

From 1235m there is also a large increase in the quartz fraction (up to 90% of total grains) and a change in lithology from mainly consolidated claystones to unconsolidated sands.

LO: *Cibicides sulzensis*, *Procerolagena gracillima*, *Uvigerina venusta*, *Uvigerina* sp., *Nonion* sp., *Florilus boueanus*, *Sphaeroidina bulloides*, *Trifarina gracilis*, *Bolboforma* cf. *badenensis*, *B. voeringensis*, *B. compressi* group.

Cassidulina teretis - Cibicides grossus - Melonis barleeanum Assemblage

Interval: 1210m-880m

Age: late Pliocene

Lithostratigraphic unit: Naust Formation

Foraminifers/g: 5-20

Species/sample: 24-37

Although it is still dominated by the nominate taxa, both the diversity and abundance of this assemblage improve. Other taxa that have their first occurrence or become abundant within this assemblage are *Quinqueloculina seminulum*, *Elphidium umbilicatum*, *E. excavatum* forma *clavata* and several buliminids. There is a distinct decrease in the abundance of *Melonis barleeanum* towards the top of the assemblage.

LO: *Sigmoilopsis schlumbergi*, *Cribroelphidium bartletti*, *E. groenlandicum*, *E. macellum*, *Buccella tenerrima*, *Lenticulina thalmanni*, *Vaginulina spinigera*, *Pyrgo williamsoni*, *P. rotalaria*, *Gyroidina soldanii*, *G. soldanii mamillata*, *Dentalina subsoluta*, *D. baggi*, *Oolina globosa*.

Elphidium excavatum forma *clavata - Cassidulina teretis - Cibicides grossus* Assemblage

Interval: 860-560m

Age: late Pliocene

Lithostratigraphic unit: Naust Formation

Foraminifers/g: 1.49-39.05

Species/sample: 11-49

Apart from the nominate taxa several species of *Fissurina* and *Oolina* appear in this assemblage. At the bottom of the assemblage there is an acme of *Trifarina angulosa*. Although diversity is still quite high, abundance may be low due to the high sedimentation rates. At the top of the assemblage the occurrence of *Cibicides grossus* indicates an upper Pliocene age.

4.2.3 Well 6407/7-2 (Fig. 12)

Position N: 64°15'26.39"

Position E: 07°10'42.65"

Water depth 338m

Trochammina ruthven-murrayi - Spiroplectammina spectabilis Assemblage

Interval: 1970m-1870m

Age: late Paleocene

Lithostratigraphic unit: Flatøy Group/Skomvær Group

Foraminifers/g:7-14

Species/sample: 30-41

A diverse and abundant assemblage in which the foraminifers have, in general, a finely grained and smoothly finished wall. The base is marked by the appearance of large numbers of extremely coarse grained *Recurvoides* cf. *gerochi*. Other taxa appearing in high numbers include *Saccammina placenta, Reticulophragmium paupera, Cribrostomoides* spp., *Recurvoides* spp. and several ammodiscids i.e. typical 'flysch type' foraminifers. Tubular forms are numerically dominant. To 1960m some of the foraminifers especially *Recurvoides* cf. *gerochi* have a green or orange colouring. From 1950m to 1900m they often have a light brown to dark brown tinge, while from 1890m to 1870m they often have a green colour. Thereafter the foraminifers are white to cream in colour. The top of the assemblage is marked by the LO of *T. ruthven-murrayi* and the LCO of *S. spectabilis*. These two events as well as the presence of large numbers of *Saccamina placenta* place the assemblage in the upper Paleocene.

LO: *T. ruthven- murrayi , Hormosina excelsa, Hyperammina* spp., *Kalamopsis grzybowskii, Saccammina sphaerica, Bigenerina* sp., *Haplophragmoides horridus Trochammina globigeriniformis, T. subvesicularis, Trochammina* sp. 3 (Charnock and Jones, 1990), *Trochammina* sp. 4 (Charnock and Jones, 1990), *Trochamminopsis pseudovesicularis, Paratrochamminoides heteromorphus, P. deformis, Arenobulimina* sp., *Plectinella munda, Rzehakina epigona, Ammolagena clavata.*

Impoverished interval

Interval: 1860m-1780m

Age: early Eocene/late Paleocene

Lithostratigraphic unit: Skomvær group

Foraminifers/g: 1-2

Species/sample: 2-12

There is a dramatic decrease in abundance and diversity in this assemblage with only a few scattered occurrences of foraminifers. Siliceous microfossils are also not observed. Since there are no age diagnostic microfossils in the assemblage its age is derived from the underlying and overlying assemblages.

LO: *Ammobaculites deflexus.*

SERIES	Depth (m)	EVENTS	ASSEMBLAGES
upper Pliocene	900	◀ LCO *C. grossus*	*Cibicides grossus* *Cibicides lobatulus* *Elphidium excavatum* forma *clavata*
	1000		*Melonis barleeanum* *Cassidulina teretis* *Cibicides grossus*
?lo. Pliocene/ Miocene		◀ Calcareous faunas	Barren
	1100	◀ *Spirosigmoilinella compressa*	
?Miocene/ upper Oligocene		◀ *Cyclammina placenta*	Impoverished
	1200	◀ Tubular forms	
? lower Oligocene		◀ *Karrerulina horrida*	*Spirosigmoilinella compressa*
	1300	◀ *G. charoides* *S. spectabilis*	
upper mid Eocene		◀ *Ammoshaeroidina pseudopauciliculata*	*Glomospira charoides*
	1400	◀ *R. amplectens*	
mid Eocene	1500		Impoverished
	1600		*Reticulophragmium amplectens*
		◀ *Spiroplec. navarroana* *Ammomarg. aubertae* *Karrerulina conversa* *Haplophragmoides kirki*	
lower mid Eo.- up. lower Eocene	1700	◀ *Saccammina placenta* *S. patagonica*	*Subbotina patagonica* *R. amplectens*
lowest Eocene			*Coscinodiscus spp.*
lower Eocene/ upper Paleocene	1800		Impoverished
upper Paleocene	1900	◀ *T. ruthven-murrayi* LCO *S. spectabilis*	*Trochammina ruthven-murrayi* *Spiroplectammina spectabilis*

◀ Last occurrence
◀ First occurrence

Figure 12. Assemblages and LOs for Well 6407/7-2

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Coscinodiscus spp. Assemblage (diatom)

Interval: 1770m-1730m

Age: earliest Eocene

Lithostratigraphic unit: Skomvær Group

Foraminifers/g: 1-7

Species/sample: 5-25

Within this assemblage diversity and abundance are once again relatively low. Although some foraminifers from the first assemblage start to reappear, no age diagnostic foraminifers are observed. There is, however, a maximum in the number of the diatoms *Coscinodiscus* spp. Assemblages with large numbers of *Coscinodiscus* spp. have previously been described by Gradstein *et al.* (1994) and Gradstein and Bäckström (1996) and have been assigned an earliest Eocene age (Ypresian). Within this assemblage radiolarians also start to be seen.

LO: *Recurvoides* sp. 1, *Reticulophragmium intermedia.*

Subbotina patagonica (planktic foraminifera)- *Reticulophragmium amplectens* Assemblage

Interval: 1720m-1670m

Age: early mid Eocene to late early Eocene

Lithostratigraphic unit: Sklinna Group

Foraminifers/g: 6-10

Species/sample: 29-36

A return to an abundant and diverse assemblage. Within this assemblage the planktic foraminifer *S. patagonica* (often pink or red in colour) has an acme appearance near the base of the assemblage. *Reticulophragmium amplectens* is present throughout. *Karrerulina conversa, K. horrida* and *Ammomarginulina aubertae* all have acme occurrences within this assemblage. Ammodiscids are also present although in lower numbers than before. Gradstein *et al.* (1994) and Gradstein and Bäckström (1996) describe similar assemblages with high numbers of *S. patagonica* from Halten Bank and the Northern North Sea. They gave their assemblages an age of Lower Eocene (Ypresian). *Ammomarginulina aubertae* is characteristic of the lower Mid Eocene NSR5 assemblage of Gradstein and Bäckström (1996) and the LO of *Spiroplectammina navarroana* is in the lower/mid Eocene. The top of the assemblage is marked by a high number of LOs.

Siliceous microfossils although present are not abundant.

LO: *Ammomarginulina aubertae, Hyperammina/Hormosina* fragments, *Ammodiscus pennyi, A. tenuissimus, A. peruvianus, Glomospira diffundens, G. glomerata, G. gordialis, G. irregularis, Haplophragmoides* cf. *kirki* (coarse), *H. suborbicularis, H.* cf. *concavus, H. porrectus, H. stomatus, H. walteri, H. walteri excavatus, H. kirki, Haplophragmoides* sp. 1., *Cribrostomoides* sp. 1, *Evolutinella* sp., *Recurvoides* sp. 2, *Cyclammina rotundidorsata, Reticulophragmium paupera, Saccammina placenta, Conglophragmium coronatum, Spiroplectammina navarroana, Karrerulina conversa, Haplophragmoides* sp. 1, *Buzasina galeata, Recurvoides* ex. gr. *turbinatus, Recurvoides* spp., *?Recurvoides/ Cribrostomoides, Trochammina.* sp. 1 (Charnock and Jones, 1990), *Subreophax scalaris, Bigenerina* sp. 1 (Charnock and Jones), 1990.

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Reticulophragmium amplectens Assemblage
Interval: 1650m-1590m
Age: mid Eocene
Lithostratigraphic unit: Sklinna Group
Foraminifers/g: 3-12
Species/sample: 7-10

The assemblage is relatively low in diversity and abundance. It is typified by large numbers of *R. amplectens* which is often as abundant or more than the tubular forms. This change of dominance is also seen in Wells 6406/9-3 and 6406/11-1. The acme of *R. amplectens* has been observed in several other areas e.g. Poland, the Labrador Shelf-Grand Banks and ODP Site 647 and seems to occur mainly in the Mid Eocene (Gradstein and Bäckström, 1996). At the top of the assemblage there is a large increase in the number of radiolarians where they make up more than 60% of the total biogenic components.
LO: *Cribrostomoides* spp., *Trochammina altiformis, Adercotryma agterbergi.*

Impoverished interval
Interval: 1570m-1430m
Age: ?mid Eocene
Lithostratigraphic unit: Sklinna Group
Foraminifers/g: 1-3
Species/sample: 2-9

There are only sporadic appearances of foraminifers in this assemblage. Tubular forms increase in numbers in comparison with the previous assemblage and again dominate. *Cyclammina placenta* and some *Cribrostomoides* spp. are also observed along with low numbers of ammodiscids. The foraminifers are in general coarser grained than in the preceding assemblages. Radiolaria are dominant throughout the assemblage reaching abundances >90% of the total biogenic components.
LO: *Ammodiscus cretaceus, Karrerulina chapapotensis, Cystammina pauciloculata, R. amplectens.*

Glomospira charoides Assemblage
Interval: 1410m-1280m
Age: late mid Eocene
Lithostratigraphic unit: Sklinna Group
Foraminifers/g: 1-2
Species/sample: 1-6

The assemblage is impoverished. Apart from the appearance of some *G. charoides*, tubular forms also continue to be present. There are no real diagnostic foraminifers in this assemblage, but the LO of *S. spectabilis* occurs within this assemblage. Radiolarias are still dominant, again reaching

abundances of >90%.

LO: *S. spectabilis, Glomospira charoides, Trochammina globigeriniformis, Ammosphaeroidina pseudopauciloculata, Budashevaella multicamerata. Textularia* spp.

Spirosigmoilinella compressa Assemblage

Interval: 1270m-1210m

Age: ?early Oligocene

Lithostratigraphic unit: Sklinna Group

Foraminifers/g: 1-2

Species/sample: 2-6

Most of the remaining agglutinated foraminifers have their LO within this assemblage. Those that are present are fairly to very coarsely grained and are often not well preserved. *Karrerulina horrida* has its LO in the NSR7A Zone of Gradstein and Bäckström (1996) during the Lower Oligocene. Radiolaria again dominate the assemblage.

LO: Tubular forms, *K. horrida, Haplophragmoides* spp, *Cribrostomoides subglobosus, Trochammina* spp., *Reophax* spp.

Impoverished interval

Interval: 1200m-1110m

Age: ?Miocene/late Oligocene

Lithostratigraphic unit: Sklinna Group

Foraminifers/g: 0-1

Species/sample: 0-1

This part of the section is almost completely devoid of foraminifers. Other microfossils are also only present in extremely low numbers. According to Gradstein and Bäckström (1996) *Spirosigmoilinella compressa* has its LO during the Lower Oligocene to lower Upper Oligocene. A single occurence of *S. compressa* is recorded in this interval much higher up than its occurence in the previous assemblage and may therefore be reworked. Siliceous microfossils, mainly radiolarians, are still dominant.

LO: *Spirosigmoilinella compressa, Cyclammina placenta.*

Barren interval

Interval: 1100m-1060m

Age: ?early Pliocene/Miocene

Lithostratigraphic unit: Sklinna Group

Foraminifers/g: 0

Species/sample: 0

This interval contains no foraminifers. Radiolaria are observed to 1080m above which they are not recorded. Within this interval high quantities of glauconite are observed which may be correlatable to a similar period seen in Well 6407/9-3.

Melonis barleeanum - Cassidulina teretis - Cibicides grossus Assemblage

Interval: 1050m-970m
Age: late Pliocene
Lithostratigraphic unit: Sula Group
Foraminifers/g: 5-18
Species/sample: 19-23

Calcareous benthic foraminifers appear suddenly at the bottom of the assemblage with high abundance and diversity. This points to the occurrence of a hiatus at the base of the assemblage. As well as the nominate taxa, *Cibicides lobatulus* and *Trifarina fluens* are also abundant. Above 1050m shell fragments, echinoid spines and ostracods are also found. Siliceous microfossils are either absent or not important. As many of the species which show a LO in this assemblage are still extant, these last occurrences are only local.

LO: *Miliolinella subrotunda, Pyrgo williamsoni, Cassidulina crassa, Globocassidulina subglobosa, Islandiella islandica.*

Cibicides grossus - Cibicides lobatulus - Elphidium excavatum forma *clavata* Assemblage

Interval: 950m-810m
Age: late Pliocene
Lithostratigraphic unit: Sula Group
Foraminifers/g: 4-19
Species/sample: 15-29

Similar to the preceding assemblage except for the increase in the above species and the addition of *Quinqueloculina seminulum, Fissurina* spp., *Oolina* spp. and some buliminids. This small influx of *Fissurina* spp., *Oolina* spp. and *Bulimina* spp. is also seen in Wells 6407/9-3 and 6406/11-1. There is also an increase in the numbers of *Trifarina angulosa* and *T. bradyi* is recorded for the first time.

4.2.4 Well 6407/9-3 (Fig. 13)

Position N: 64°19'48.94"
Position E: 07°47'30.91"
Water Depth 279m

Spiroplectammina spectabilis - Trochammina ruthven-murrayi Assemblage

Interval: 1540m-1410m

SERIES	Depth (m)	EVENTS	ASSEMBLAGES
upper Pliocene	400		Elphidium excavatum f. clavata/ C. grossus
	500		Melonis barleeanum Cassidulina teretis E. excavatum f. clavata
	600 700		Cassidulina teretis E.excavatum f. clavata
?lower Pliocene		◄ Sphaeroidina bulloides ◄ Sigmoil. schlumbergi	Sphaeroidina bulloides
?lower Pliocene/ upper Miocene	800		Barren
mid Miocene	900	◄ Neogene Rad. flood Tubular forms ◄ G. charoides	Impoverished/ siliceous
upper mid Eocene	1000	◄ Cyclammina placenta	Glomospira charoides
up. mid- mid Eocene	1100	◄ S. spectabilis	Coarse agglutinated foraminifers
mid Eocene	1200	◄ R. amplectens ◄ Eocene Rad. flood Karrerulina conversa K. horrida	Reticulophragmium amplectens
mid/lower Eocene	1300	◄ A. aubertae Spiroplectammina navarroana	Ammomarginulina aubertae R. amplectens
lo. Eocene		◄ Aderc. agterbergi S. patagonica	Subbotina patagonica
lower Eo./ upper Pal.	1400	Rzehakina minima	Coscinodiscus spp.
upper Paleocene	1500	◄ LCO S. spectabilis T. ruthven-murrayi ◄ LCO S. placenta	Spiroplectammina spectabilis Trochammina ruthven-murrayi

◄ Last occurrence
◄ First occurrence

Figure 13. Assemblages and LOs for Well 6407/9-3

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Age: late Paleocene
Lithostratigraphic unit: Sele/Lista Formation
Foraminifers/g:19-5
Species/sample: 30-46

The assemblage is diverse and abundant and marked by a peak and the LCO of *S. spectabilis* and by the LO of *T. ruthven-murrayi* at 1420m. The foraminifers are in general finely grained and smoothly finished, well preserved and often have a dark brown to light brown colour. The assemblage is numerically dominated by tubular genera such as *Rhabdammina* and *Bathysiphon*. Other important taxa are *Karrerulina conversa* (acme), *K. horrida, Ammosphaeroidina pseudopauciloculata, Cystammina pauciloculata* and *Saccammina placenta*. Ammodiscids and trochamminids are also present in high numbers. The assemblage has the composition of a typical 'flysch type' assemblage. There is also a small acme of *Trochamminoides* spp.

An upper Paleocene age can be assigned to this assemblage due to the presence and LO of *Trochammina ruthven-murrayi* and the LCO of *Spiroplectammina spectabilis*. These two events are generally recorded during the Upper Paleocene (Gradstein and Bäckström 1996; Nagy *et al.*, in press).

LO: *Recurvoides* cf. *C. gerochi, Recurvoides* cf. *subturbinatus, Trochammina subvesicularis, Trochammina* sp. 2 (Charnock and Jones, 1990), *Trochammina* sp. 3 (Charnock and Jones, 1990), *Reticulophragmium paupera, Reticulophragmoides jarvisi, Trochamminoides dubius, T. proteus, T. subcoronatus, Paratrochamminoides deformis, Dorothia retusa, Hormosina velascoensis, Hormosina* sp., *Hyperammina elongata, Kalamopsis grzybowskii, Ammodiscus peruvianus, Haplophragmoides* sp. 1 (Charnock and Jones, 1990), *?Trochammina/ Haplophragmoides, Rzehakina minima, Arenobulimina* sp., *Hormosina ovulum ovulum, Bigenerina* sp., *Recurvoides* sp. 3.

LCO: *Spiroplectammina spectabilis.*

Coscinodiscus spp. Assemblage (diatom)

Interval: 1400m-1340m
Age: ?early Eocene/late Paleocene
Lithostratigraphic unit: Sele/Lista - Balder Formations
Foraminifers/g: 1-3
Species/sample: 14-25

A drop in diversity and abundance is accompanied by an acme in the diatoms *Coscinodiscus* spp. These are mainly pyritized although a few specimens which seem to be opalized are also seen. Benthic foraminifers are present but in reduced numbers. Tubular forms are again dominant. In contrast to the previous assemblage the foraminifers generally have a whitish yellow colour but are again relatively finely grained.

Gradstein *et al.*, (1994) and Gradstein and Bäckström (1996) placed a similar assemblage dominated by *Coscinodiscus* spp. in the Earliest Eocene (Ypresian).

LO: *Trochamminoides* spp., *Hyperammina* sp., *Glomospira* sp.

Subbotina patagonica (planktic foraminifer) Assemblage

Interval: 1320m-1300m

Age: early Eocene

Lithostratigraphic unit: Balder Formation

Foraminifers/g: 5-18

Species/sample: 39-42

A return to a diverse and abundant assemblage. Many of the same species that temporarily disappeared in the impoverished interval reappear. Ammodiscids however are present in reduced numbers. Tubes once again dominate numerically. The most notable feature of the assemblage is the sudden influx of planktic species, especially *S. patagonica*. These often have a slight pink or red colouring. This red colouring is derived from 'The Red Shale' interval at the base of the Hordeland Group (Gradstein *et al.*, 1994). An assemblage with high numbers of *S. patagonica* was also described by Gradstein *et al.*, (1994) and Gradstein and Bäckström (1996). They assigned a Lower Eocene age to this assemblage. Important benthic foraminifers in the assemblage are *Ammomarginulina aubertae, Spiroplectammina navarroana, Karrerulina conversa, K. horrida, Haplophragmoides* spp. and *Recurvoides* spp.

LO: *S. patagonica, Dorothia siegliei, Eggerella* sp., *Bigenerina* sp. 1 (Charnock and Jones, 1990), *Trochamminoides subcoronatus, T . irregularis, Hyperammina/Hormosina* fragments, *Glomospira serpens, Haplophragmoides* cf. *walteri, H.* cf. *porrectus.*

Ammomarginulina aubertae - Reticulophragmium amplectens Assemblage

Interval: 1290m-1260m

Age: mid/early Eocene

Lithostratigraphic unit: Hordaland Group

Foraminifers/g: 14.49- 7.34

Species/sample: 37-39

Again a diverse and abundant assemblage with the foraminifers being very similar to the underlying *S. patagonica* assemblage. The top of the assemblage is marked by a large number of LOs and a distinct drop in diversity and abundance. Within the assemblage radiolarians begin to become an important part of the total microfossil fauna for the first time.

Ammomarginulina aubertae is a characteristic species in the NSR6 assemblage of Gradstein and Bäckström (1996), which has an age of late Mid Eocene. It was probably restricted to the high latitudes as, at present, it has only been found in the North Sea, Norwegian Sea and Labrador Sea (Gradstein and Bäckström, 1996). The LO of *Spiroplectammina navarroana* was placed in the Lower Eocene NSR5A Zone of Gradstein and Bäckström (1996) and within the uppermost Paleocene to Earliest Eocene by Nagy *et al.*, (in press).

LO: *Ammobaculites deflexus, Hormosina excelsa, Saccammina placenta, Ammodiscus pennyi, A. tenuissimus, Glomospira diffundens, G. gordialis, Karrerulina coniformis, Cystammina*

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pauciloculata, Ammomarginulina aubertae, Haplophragmoides horrida, H. kirki, H. porrectus, H. stomatus, Haplophragmoides sp. 1, *.H.* cf. *kirki, Cribrostomoides* sp. 1, *Veleroninoides scitulus, Recurvoides* sp. 1, *Recurvoides* sp. 2, ?*Recurvoides/ Cribrostomoides, Trochammina altiformis, T. globigeriniformis, Trochammina* sp. 1 (Charnock and Jones, 1990), *Adercotryma agterbergi, Conglophragmium coronatum, Reophax* sp., *Arenobulimina* sp., *Gravellina* sp., *Spiroplectammina navarroana.*

Reticulophragmium amplectens Assemblage

Interval: 1240m-1120m

Age: mid Eocene

Lithostratigraphic unit: Hordaland Group

Foraminifers/g: 9-5

Species/sample: 6-19

This assemblage is marked by an acme and LO of *R. amplectens*. This taxon is often as or more abundant than the tubular forms. Radiolaria become increasingly abundant throughout the assemblage having a peak of > 90% at 1220m. This may represent the 'Eocene Radiolarian Flood' of Gradstein *et al.* (1988).

The LO of *Karrerulina conversa* was placed in the upper Lower Eocene to lower Mid Eocene by Gradstein and Bäckström (1996). Their *R. amplectens* Zone is largely upper Mid Eocene possibly extending into the Upper Eocene.

LO: *Budashevaella multicamerata, Cyclammina rotundidorsata, Recurvoides* ex. gr. *turbinatus, Trochammina* sp., *Ammodiscus cretaceus, Karrerulina conversa, K. horrida, Haplophragmoides walteri, R. amplectens, Karrerulina chapapotensis, Ammosphaeroidina pseudopauciloculata, Haplophragmoides suborbicularis.*

Coarse agglutinated foraminifers Assemblage

1100m-1080m

Age: late mid to mid Eocene

Lithostratigraphic unit: Hordaland Group

Foraminifers/g: 1-2

Species/sample: 6-12

The assemblage typically has low diversity and abundance. The majority of foraminifers are medium to very coarsely grained. Radiolaria are again dominant representing up to 50 to 80% of the total assemblage.

Spiroplectammina spectabilis normally has a total range of Campanian to uppermost Eocene but probably has its LO on Halten Bank around the Mid Eocene. (Gradstein and Bäckström, 1996)

LO: *S. spectabilis, Glomospira irregularis.*

Glomospira charoides Assemblage

Interval: 1060m-940m

Age: late mid Eocene

Lithostratigraphic unit: Hordaland Group

Foraminifers/g: 1-4

Species/sample: 3-7

There is a *G. charoides* acme within this assemblage, which also comprises tubular forms. Radiolaria are again dominant.

LO: *Cyclammina placenta, Cyclammina* sp., *Ammodiscus* sp., *Glomospira charoides, Haplophragmoides* cf. *concavus.*

Impoverished/ siliceous interval

Interval: 930- 900m

Age: mid Miocene

Lithostratigraphic unit: Hordaland group

Foraminifers/g: 0-1

Species/sample: 0-3

A more or less barren zone. At the top of the interval there is a flood of radiolarians which may be correlatable to the Neogene radiolarian flood of Gradstein *et al.,* (1988). Above this they decrease rapidly in abundance and after 850m are extremely rare.

LO: Tubular forms, *Textularia* sp., *Haplophragmoides* sp., *Cribrostomoides subglobosus.*

Barren interval

Interval: 890m-790m

Age: ?early Pliocene/late Miocene

Lithostratigraphic unit: Hordaland/Nordland Group

Foraminifers/g: 0

Species/sample: 0

This interval is entirely barren of foraminifers. At the base pyritized burrows/worm tubes are very abundant. Above 850m the interval is barren of all microfossils. From 840m to 770m glauconite is extremely abundant. This may be correlatable with a similar interval recorded in well 6407/7-2.

LO: None

Sphaeroidina bulloides Assemblage

Interval: 780m-750m

Age: ?early Pliocene

Lithostratigraphic unit: Nordland Group

Foraminifers/g: 1-2
Species/sample: 25-9

Diversity and abundance start to increase within this assemblage with *Melonis barleeanum* and *Cassidulina teretis* are being abundant. Much of the upper Miocene and lower Pliocene sediments may be missing from this well. There are very few diagnostic species present and those that are indicate an lower to upper Pliocene age.

LO: *Sigmoilopsis schlumbergeri, Elphidium incertum, Florilus aequalis, Cassidulina obtusa, Hoeglundina elegans, Cancris auricularis, Pullenia quinqueloba, Sphaeroidina bulloides, Plectofrondicula advena.*

Cassidulina teretis - *E. excavatum* forma *clavata* Assemblage

Interval: 740m- 550m
Age: late Pliocene
Lithostratigraphic unit: Nordland Group
Foraminifers/g: 1-2
Species/sample: 16-22

Calcareous foraminifers begin to become diverse and abundant and are much better preserved than in the previous assemblages. Buliminids also start to become important as well as *Cibicides lobatulus*. *Melonis barleeanum* shows a slight decrease in abundance.

LO: *Pyrgo williamsoni.*

M. barleeanum - *Cassidulina teretis* - *Elphidium excavatum* forma *clavata* Assemblage

Interval: 540m-470m
Age: late Pliocene
Lithostratigraphic unit: Nordland group
Foraminifers/g: 3-4
Species/sample: 30

Diversity and abundance again increase in this assemblage which is dominated by the nominate taxa. *Quinqueloculina seminulum* has its FO in this assemblage. According to Gradstein and Bäckström (1996) *Trifarina fluens* has a local LO in the upper Pliocene.

LO: *Quinqueloculina agglutinata, Cibicides dutemplei, C. refulgens, Trifarina fluens, Cassidulina norcrossi, Globocassidulina subglobosa, Lenticulina gibba, Astacolus hyalacrulus.*

E. excavatum forma *clavata* - *Cibicides grossus* Assemblage

Interval: 460- 390m
Age: late Pliocene
Lithostratigraphic unit: Nordland group

Foraminifers/g: 2-7
Species/sample: 38-41

This assemblage is marked by the acmes of *E. excavatum* f. *clavata* and *C. grossus* although, as in Well 6407/8-1, the actual numbers of *C. grossus* are low. The presence of *C. grossus* places this assemblage in the Pliocene. A number of *Fissurina* and *Oolina* species also appear.

4.3 Proposed biostratigraphic scheme for the Halten Terrace area

Using the observations from the four wells a composite biostratigraphy has been created. Although the emphasis of this work is upon benthic foraminifers, in some intervals they are not present or those that are are not age diagnostic. Therefore in order to present a scheme which is as complete as possible and contains easily identifiable and, where possible, abundant markers, planktic foraminifers, diatoms, bolboforms and radiolarians have also been incorporated into the biostratigraphy. Such an integrated approach is commonly used when dealing with cutting samples which may often be small in quantity and variable in quality and has been successfully applied by Gradstein *et al.* (1994) and Gradstein and Bäckström (1996) to the Halten Bank and North Sea area.

Figure 14 shows the assemblages and their characteristic microfossils. The lower Paleocene and upper Eocene were not observed in the wells studied here.

1. *Trochammina ruthven-murrayi* **-** *Spiroplectammina spectabilis* **Assemblage**
Age: Late Paleocene
Diverse and abundant assemblage. The foraminifers have finely grained and smoothly finished tests - often green or brown in colour. The top of the assemblage is marked by the LCO of *S. spectabilis*. In general the foraminifers are typical 'flysch type' faunas. *Rzehakina minima, Subreophax* spp. and *Trochamminoides* spp. are generally confined to the assemblage.

2. Impoverished Assemblage
Age: late Paleocene/early Eocene
Low abundance and low diversity assemblage with foraminifers similar to those from Assemblage 1.
3. *Coscinodiscus* **spp.Assemblage**
Age: earliest Eocene
Generally low diversity and abundance assemblage characterised by the appearance of large numbers of pill box shaped diatoms, *Coscinodiscus* spp. These are generally pyritized. The foraminifers that are seen are again those from Assemblage 1.

	Assemblages	Characteristic microfossils	
L. Plio.	Cibicides grossa Elphidium excavatum f. clavatum Melonis barleeanum/ Cassidulina teretis	Cibicides grossa Elphidium excavatum f. clavatum Melonis barleeanum Cassidulina teretis Cibicides lobatulus Bulimina spp. Fissurina spp. Oolina spp. Elphidium spp.	14
E.Plio.	Sphaeroidina bulloides		
L.Mio.	Bolboforma metzmacheri		
M.Mio.	Martinottiella communis Bolboforma spp.	Melonis barleeanum Cassidulina teretis Cibicides lobatulus Trifarina spp. Globocassidulina globosa Elphidium spp.	13
E Mio.	Unzoned	Sphaeroidina bulloides Melonis barleeanum Cassidulina teretis	12
		Bolboforma metzmacheri Melonis barleeanum Cassidulina teretis	11
		Martinottiella communis Ehrenbergina variabilis Bolboforma badenensis Bolboforma voeringensis Bolboforma compressi group	10
L. Olig.	Interval	Occasional calcareous benthics Radiolarians	9
E.Olig.	Turrilina alsatica Spirosigmoilinella compressa	Turrilina alsatica Spirosigmoilinella compressa Coarse agglutinated foraminifers	8
L.Eo.	/////	Glomospira charoides Cyclammina placenta	7
	Glomospira charoides	Reticulophragmium amplectens Cribrostomoides spp. Recurvoides spp. Haplophragmoides spp.	6
M.Eo.	Reticulophragmium amplectens	Karreriella conversa Karreriella horrida Ammomarginulina aubertae Spiroplectammina navarroana Reticulophragmium amplectens Haplophragmoides kirki Haplophragmoides porrectus Recurvoides spp.	5
E.Eo.	Karreriella spp. Spiroplectammina navarroana	Subbotina patagonica Karreriella conversa Karreriella horrida Ammomarginulina aubertae Spiroplectammina navarroana Reticulophragmium intermedia	4
	Subbotina patagonica		
	Coscinodiscus spp.	Coscinodiscus spp. foraminifers from Assemblage 1	3
	Impoverished		
L.Pal.	Trochammina ruthven-murrayi	Scattered appearence of foraminifers from Assemblage 1	2
	Spiroplectammina spectabilis	Trochammina ruthven-murrayi Spiroplectammina spectabilis Saccammina placenta Trochamminoides spp. Ammodiscus spp. Glomospira spp. Haplophragmoides walteri Bathysiphon spp. Rhabdammina spp.	1
E. Pal.	/////		

Figure 14. Assemblage zones and characteristic taxa for the proposed Halten Terrace biostratigraphy

4. *Subbotina patagonica* Assemblage

Age: early Eocene

The assemblage is characterised by an influx of the planktic foraminifer *S. patagonica*. These often have a pink colour. There is also a return to high diversity and abundance. Many of the foraminifers recorded are again similar to assemblage 1, although ammodiscids decrease in importance. *Reticulophragmium intermedia* and *Buzasina galeata* are generally confined to this assemblage. The benthic foraminifers are again finely grained. In contrast to assemblage 1 the tests are usually white to cream in colour.

5. *Karrerulina* spp. - *Spiroplectammina navarroana* Assemblage

Age: early Eocene

Again an abundant and diverse assemblage with acmes in the nominate taxa. *Haplophragmoides kirki* and *H. porrectus* are also important. *Reticulophragmium amplectens* also appears in the assemblage but has its acme in the overlying one.

6. *Reticulophragmium amplectens* Assemblage

Age: mid Eocene

Diversity tends to decrease within this assemblage as *R. amplectens* is very dominant often more so than the tubular forms. Other typical foraminifers include *Cribrostomoides sp. Recurvoides* spp. *Budashevaella multicamerata* and *Ammomarginulina aubertae*. Siliceous microfossils, mainly radiolarians, also start to appear within this assemblage in large numbers.

7. *Glomospira charoides* Assemblage

Age: late mid Eocene

Abundance and diversity decrease further within this assemblage. The foraminifers also tend to be less finely finished and slightly coarser grained. The most noticeable feature of the assemblage is the small influx of the nominate taxa. Siliceous microfossils are again dominant.

8. *Turrilina alsatica* - *Spirosigmoilinella compressa* Assemblage

Age: early Oligocene

A low abundance and diversity assemblage. Apart from the two nominate taxa *Rotaliatina bulimoides* is also occasionally recorded. Coarse agglutinated foraminifers and some badly preserved calcareous benthics may also be present. Siliceous microfossils again dominate.

9.unzoned interval

Age: ?late Oligocene/early Miocene

Extremely poor assemblages, there may also be barren areas. A few badly preserved calcareous foraminifers may be observed. Siliceous microfossils, especially radiolarians, are dominant.

10. *Martinottiella communis - Bolboforma* spp. Assemblage

Age: mid Miocene

Generally low abundance and low diversity assemblages, with the appearance of the above foraminifer and some Mid Miocene Bolboforms. *Ehrenbergina variablis* may also be present.

11. *Bolboforma metzmacheri* Assemblage

Age: late Miocene

The assemblages start to improve in abundance and diversity. The foraminifers recorded are calcareous benthics. *Melonis barleeanum* and *Cassidulina teretis* and *Elphidium* spp. are often seen. Siliceous microfossils start to decrease in abundance within this assemblage.

12. *Sphaeroidina bulloides* Assemblage

Age: early Pliocene

Although still quite low, diversity and abundance show an increase once more. Calcareous foraminifers are again dominant. *Sigmoilopsis schlumbergeri* is also observed within this assemblage. Siliceous microfossils are unimportant.

13. *Melonis barleeanum - Cassidulina teretis* Assemblage

Age: late Pliocene

Generally high diversity and abundance assemblage dominated by the nominate taxa. Other taxa typically recorded include *Trifarina* spp. *Globocassidulina subglobosa*, *Cibicides lobatulus* and *Elphidium* spp.

14. *Cibicides grossus - Elphidium excavatum* forma *clavata* Assemblage

Age: late Pliocene

Again a high diversity and abundance assemblage. Many of the foraminifers from Assemblage 13 are also observed here although *Melonis barleeanum* may show a decrease in abundance. The nominate taxa are dominant. Within this assemblage there is also an increase in the abundance of *Fissurina* spp. *Oolina* spp. and buliminids. *Quinqueloculina seminulum* is recorded for the first time.

4.3.1 Correlation of Halten Terrace wells

The four wells from this study have been correlated with one another (Fig. 15). The LOs and LCOs of common foraminifers are shown, The correlation of the *Fissurina* spp, *Oolina* spp. interval is also shown although it does not occur in all wells. Likewise the glauconite horizon is only clearly seen within Wells 6407/7-2 and 6407/9-3, however a tentative correlation to glauconite horizons in the other two wells is shown. The horizon '*Bigenerina* sp.', refers to an interval in Wells 6407/7-2 and 6407/9-3 where *Bigenerina* sp. appears whith typically black coloured sutures.
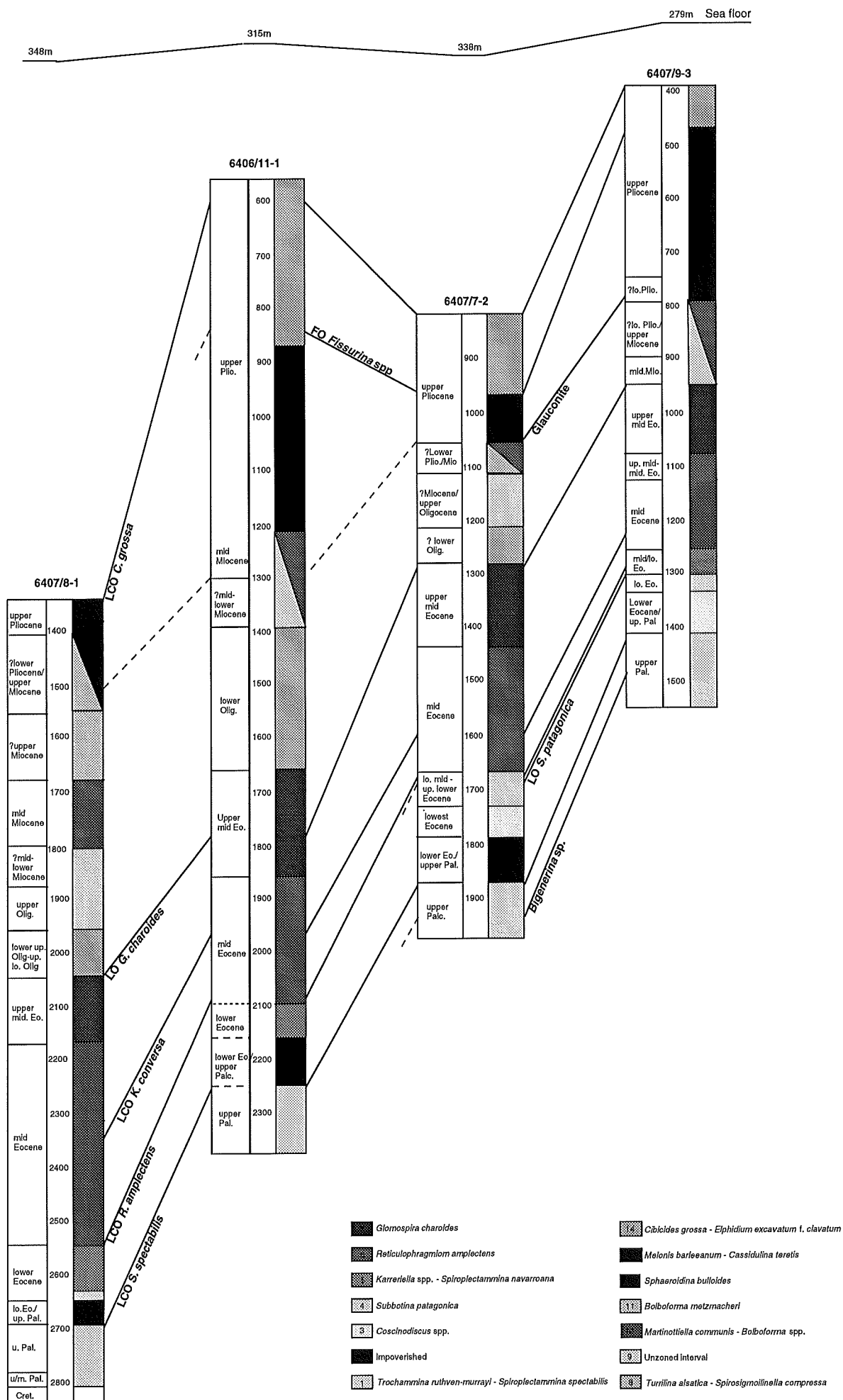
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Figure 15. Correlation of Halten Terrace wells.

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4.4 Review of previous biostratigraphical schemes

Verdenius and Van Hinte (1983) worked with Mid Eocene to Mid Miocene DSDP material from the Vøring Plateau, Jan Mayen Ridge and Lofoten Basin. They produced a scheme of a 'rich' faunal association with four agglutinated zones and a 'poor' association which was divided into three zones and concluded that the occurrence of agglutinated foraminiferal assemblages and the very low number of calcareous forms observed pointed to a harsh, low nutrient, deep sea environment. Later work however, (ODP Leg 104 etc.) has provided evidence suggesting that high fertility and upwelling conditions prevailed at the time, and that the deposition of siliceous plankton provided an abundant food supply. The decay of such organisms would have led to the lowering of pH within the Norwegian-Greenland Sea, consequently leading to an increase in the dissolution of calcareous tests and hampering calcite precipitation (Berggren and Schnitker, 1983; Osterman and Qvale, 1989).

Osterman and Qvale (1989) during ODP Leg 104 produced a scheme of seven assemblage zones with samples ranging from the Eocene to Holocene. Eocene to Mid Miocene assemblages were found to be dominated by agglutinated foraminifers (a dissolution assemblage rather than an original living assemblage). From the Upper Miocene to Pliocene the assemblages were diverse and dominated by calcareous forms, while the Upper Pliocene to Holocene was characterised by many barren intervals and samples containing shallow water species as well as ice rafted material. These later assemblages probably represent glacial periods while interglacial periods were characterised by true oceanic foraminiferal assemblages and no coarse clastic material.

Kaminski *et al.* (1990) further studied material from ODP Leg 104, Site 643 concentrating on Eocene to Lower Miocene sediments. Their scheme consisted of five agglutinated assemblage zones. They found diverse and abundant assemblages in the Eocene and Lower Oligocene. During the Upper Oligocene to Lower Miocene there was a drop in both abundance and diversity.

Hulsbos *et al.* (1989), produced a local scheme of three zones for the Lower Eocene of the Vøring Plateau using DSDP Site 338 material. Zones one and two were either barren (Zone 1) or contained calcareous benthics i.e. 'Midway' type faunas (Zone 2). Zone 3 contained a mixture of calcareous benthics at its base and an increase in the number of agglutinated foraminifers towards the top of the zone.

Poole and Vorren (1993) presented a scheme of four main assemblage zones containing nine subzones from the Upper Oligocene to Quaternary of the mid Norwegian shelf using cutting samples. The Miocene to Pliocene assemblages were dominated by calcareous benthics while the Oligocene contained sparse foraminifers both agglutinated and calcareous but abundant radiolarians and diatoms.

Gradstein *et al.* (1992), Gradstein *et al.* (1994) and Gradstein and Bäckström (1996) produced a composite biostratigraphy for the northern North Sea area and Halten Bank incorporating both foraminifers and dinoflagellates. Their material also consisted of cuttings. To produce the biostrat-

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igraphy they used two quantitative biostratigraphy software programs: 1. Ranking and scaling which considers the stratigraphic order of all (pairs of) events in well simultaneously and calculates the most likely sequence of events (Gradstein and Bäckström, 1996) and 2. a probabilistic graphic zonation using the program STRATCOR. For further information on how these programs work see references cited above.

Nagy *et al.* (in press) produced a biostratigraphic scheme for the Paleogene of the Southwest Barents Sea again using mainly cutting material. They used a combination of foraminifers, palynomorphs and diatoms and their biostratigraphy consisted of six palynomorph and foraminiferal assemblages and five diatom assemblages where the foraminiferal assemblages contain only agglutinated foraminifers. In the Upper Palaeocene to earliest Eocene (Assemblages 6-2) the assemblages are diverse. In the Lower Eocene (Assemblage 1) diversity shows a sharp decrease.

Osterman and Spiegler (1996) produced an agglutinated benthic biostratigraphy for Sites 909 and 913 from ODP Leg 151 in the Fram Strait and Greenland Basin. At Site 909 the zones range from the Middle to Upper Miocene and consist of four assemblages dominated by *Reticulophragmium amplectens* and *R.* ex gr. *rotundidorsata*. At Site 913 five zones were distinguished ranging from the Eocene to Miocene dominated by either *R. amplectens* or *Reophax abyssorum*. Osterman (1996) during the same Leg also investigated the Pliocene and Quaternary foraminifers from Site 910 on the Yermak Plateau. Four assemblage zones dominated by calcareous benthics were constructed.

Outside the Norwegian Sea a large number of studies have concentrated on the North Sea and Labrador Sea (e.g. Miller *et al.*, 1982; King 1983; Gradstein and Berggren 1981; Gradstein *et al.*, 1988; Kaminski *et al.*, 1989a, Kaminski *et al.*, 1989b). Those most useful to this work are discussed below.

Seidenkrantz (1992) used well cuttings and core material from the northernmost North Sea along the southern Norwegian shelf and produced a scheme of four zones covering the Pliocene and Pleistocene. The assemblages contained almost exclusively calcareous foraminifers.

For the North Sea area the work of King (1983, 1989) which has zones based on agglutinated and calcareous foraminifers as well as diatoms and bolboforms for the Cenozoic is useful as it provides links to other biostratigraphies in the North Sea area. The scheme has separate zonations for calcareous benthics (NSB) for agglutinated foraminifers (NSA) and planktic microfossils (NSP) including foraminifers, diatoms and bolboforms.

Kaminski *et al.* (1989a) produced a benthic foraminiferal biostratigraphy for the Labrador Sea based on data from ODP Site 647 and DSDP Site 112. Seven assemblages for the Paleogene were recognised. The assemblages changed from predominantly agglutinated in the Eocene to predominantly calcareous in the Oligocene with two significant turnovers being recorded at the Ypresian/Lutetian boundary and the Eocene/Oligocene boundary.

Kaminski *et al.* (1989b) studied Neogene samples from ODP Sites 645, 646 and 647 in Baffin Bay

and the Labrador Sea. At Site 645 in Baffin Bay the assemblages were endemic and could not be correlated with other sites in the Atlantic. The foraminifers recorded were mostly agglutinated during the Miocene and calcareous during the Pliocene. At Sites 646 and 647 in the Labrador Sea changes in the assemblages were used to infer important palaeoceanographic events.

4.5 Comparison with probabilistic optimum sequence

A probabilistic optimum sequence of LOs has been calculated in a study by Gradstein and Bäckström (1996) . This study uses statistical methods to merge the actual LOs observed in 26 wells on the Halten Bank and the North Sea to produce a theoretical probabalistic composite sequence of LOs. This composite sequence represents the most likely common sequence of extincions based on the available data. The LO sequences observed in each well in this study were correlated with this optimum sequence - the results of the comparison can be seen in figures 16 to 19.

In each diagram the numbers on the X axis show the species numbers in this study while those on the Y axis are the numbers from the optimum sequence. A point has been plotted at each intersection. Were the order of LOs in both sequences identical, these points would all lie on a straight line. The degree of ´fit´ of a best straight line in these diagrams represents the degree of correlation between the two sequences. An LO in this study which is later than that in the optimum sequence appears above the best fit line one which is earlier would appear below.

Optimum Sequence	
Elphidium clavatum	240
Trifarina fluens	316
Cibicidoides grossa LCO	159
Cibicidoides pachyderma	330
Radiolarians/diatoms flood	91
Martinotiella cylindrica	219
Coarse agglutinated spp.	25
Cyclammina placenta	97
Spirosigmoilinella compressa	182
Cyclammina rotundidorsata	183
Karreriella horrida	262
Adercotryma agterbergi	289
Haplophragmoides walteri	261
Reticulophragmium amplectens	29
Ammosph. pseudopauciloculata	32
Ammomarginulina aubertae	263
Haplophragmoides kirki	260
Reticulophragmoides jarvisi	291
Spiroplectammina spectabilis LO	68
Karreriella conversa	264
Reticulophragmium intermedia	175
Spiroplectammina navarroana	54
Coscinodiscus spp.	22
Cystammina pauciloculata	136
Rzehakina minima	105
Spiroplectammina spectabilis LCO	57
Saccammina placenta	310
Hormosina excelsa	134
Trochammina ruthven murrayi	129

Well 6406/8-1

Last Occurrence too low in Well 6406/8-1
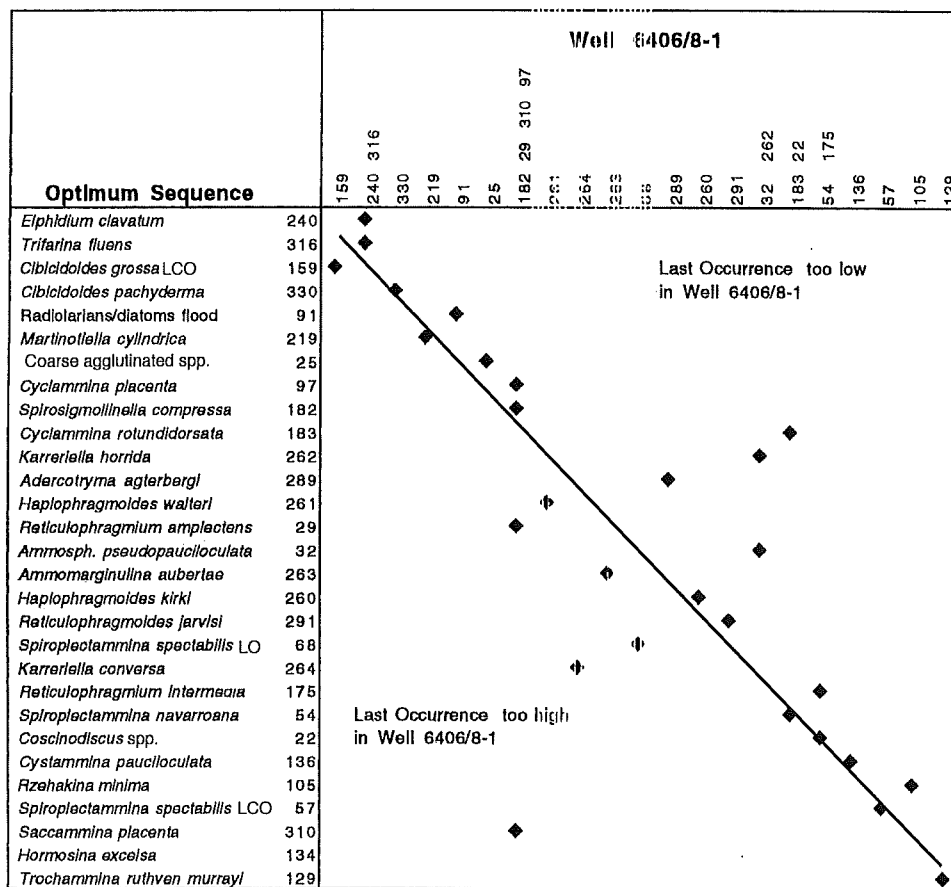
Last Occurrence too high in Well 6406/8-1

Figure 16. Correlation of Well 6406/8-1 with the optimum sequence of Gradstein and Bäckström (1996). The numbers on the Y axis refer to a unique dictionary number for that species. The corresponding numbers on the X axis refer to the same species in this study.
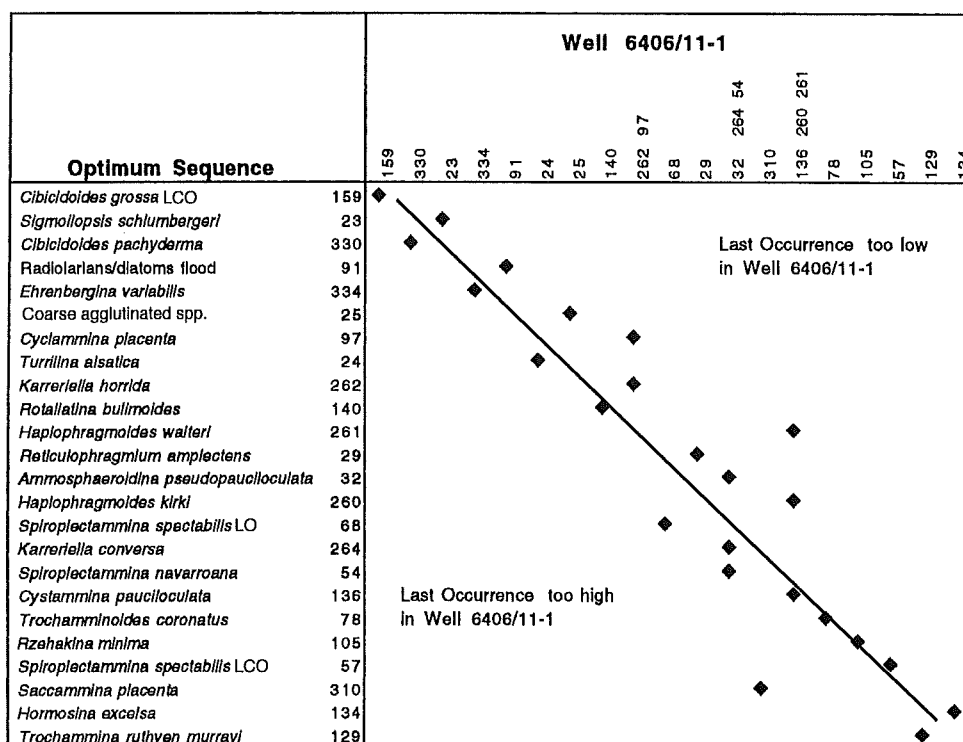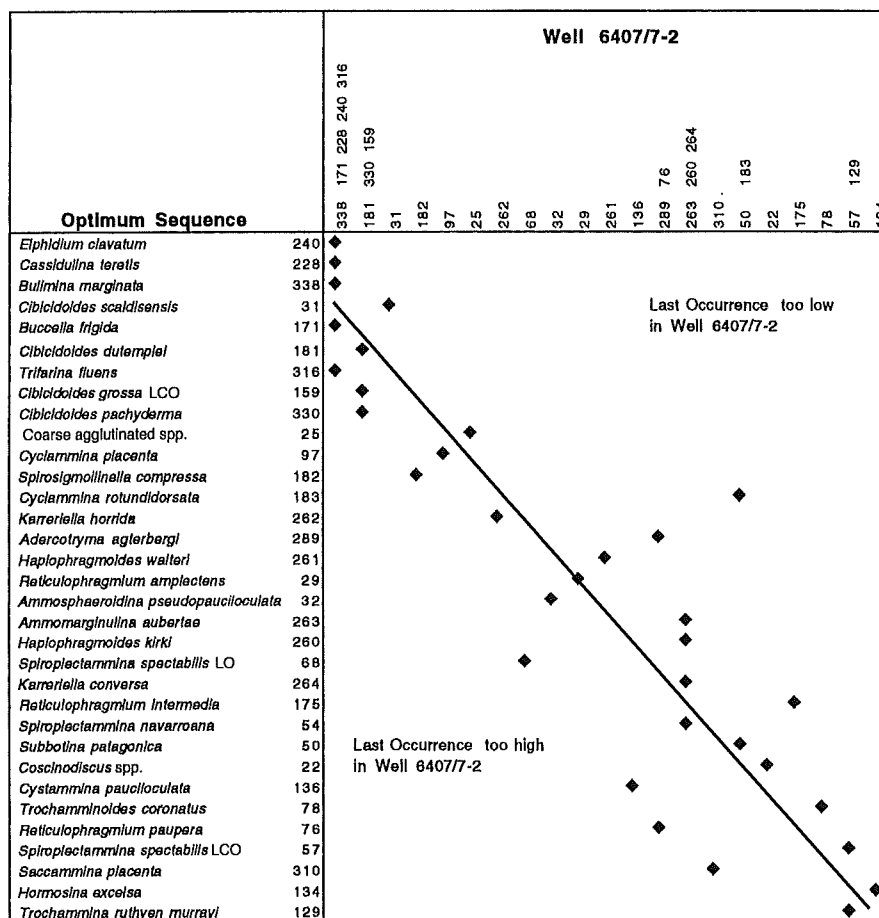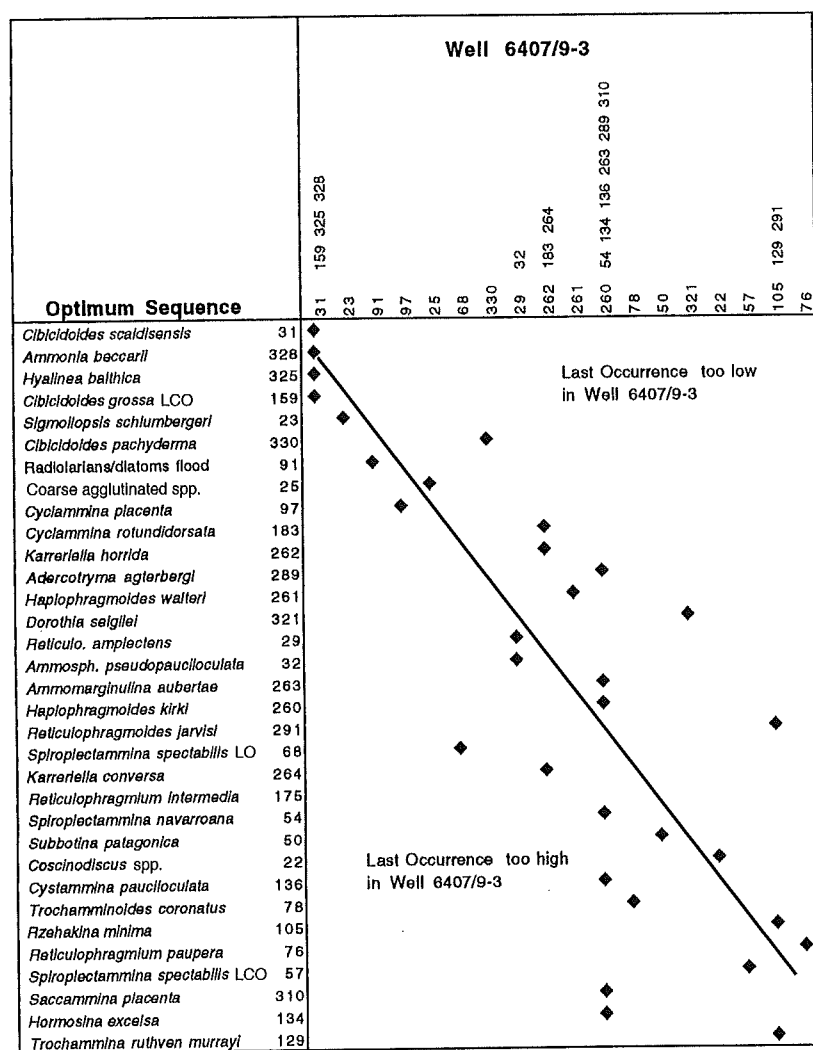
Optimum Sequence		Well 6406/11-1
Cibicidoides grossa LCO	159	
Sigmoilopsis schlumbergeri	23	
Cibicidoides pachyderma	330	
Radiolarians/diatoms flood	91	
Ehrenbergina variabilis	334	
Coarse agglutinated spp.	25	
Cyclammina placenta	97	
Turrilina alsatica	24	
Karreriella horrida	262	
Rotaliatina bulimoides	140	
Haplophragmoides walteri	261	
Reticulophragmium amplectens	29	
Ammosphaeroidina pseudopauciloculata	32	
Haplophragmoides kirki	260	
Spiroplectammina spectabilis LO	68	
Karreriella conversa	264	
Spiroplectammina navarroana	54	
Cystammina pauciloculata	136	
Trochamminoides coronatus	78	
Rzehakina minima	105	
Spiroplectammina spectabilis LCO	57	
Saccammina placenta	310	
Hormosina excelsa	134	
Trochammina ruthven murrayi	129	

Figure 17. Correlation of Well 6406/11-1 with the optimum sequence of Gradstein and Bäckström (1996). The numbers on the Y axis refer to a unique dictionary number for that species. The corresponding numbers on the X axis refer to the same species in this study.

Optimum Sequence		Well 6407/7-2
Elphidium clavatum	240	
Cassidulina teretis	228	
Bulimina marginata	338	
Cibicidoides scaldisensis	31	
Buccella frigida	171	
Cibicidoides dutemplei	181	
Trifarina fluens	316	
Cibicidoides grossa LCO	159	
Cibicidoides pachyderma	330	
Coarse agglutinated spp.	25	
Cyclammina placenta	97	
Spirosigmoilinella compressa	182	
Cyclammina rotundidorsata	183	
Karreriella horrida	262	
Adercotryma agterbergi	289	
Haplophragmoides walteri	261	
Reticulophragmium amplectens	29	
Ammosphaeroidina pseudopauciloculata	32	
Ammomarginulina aubertae	263	
Haplophragmoides kirki	260	
Spiroplectammina spectabilis LO	68	
Karreriella conversa	264	
Reticulophragmium intermedia	175	
Spiroplectammina navarroana	54	
Subbotina patagonica	50	
Coscinodiscus spp.	22	
Cystammina pauciloculata	136	
Trochamminoides coronatus	78	
Reticulophragmium paupera	76	
Spiroplectammina spectabilis LCO	57	
Saccammina placenta	310	
Hormosina excelsa	134	
Trochammina ruthven murrayi	129	

Figure 18. Correlation of Well 6407/7-2 with the optimum sequence of Gradstein and Bäckström (1996). The numbers on the Y axis refer to a unique dictionary number for that species. The corresponding numbers on the X axis refer to the same species in this study.

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Well 6407/9-3

Last Occurrence too low
in Well 6407/9-3

Last Occurrence too high
in Well 6407/9-3

Optimum Sequence	
Cibicidoides scaldisensis	31
Ammonia beccarii	328
Hyalinea balthica	325
Cibicidoides grossa LCO	159
Sigmoilopsis schlumbergeri	23
Cibicidoides pachyderma	330
Radiolarians/diatoms flood	91
Coarse agglutinated spp.	25
Cyclammina placenta	97
Cyclammina rotundidorsata	183
Karreriella horrida	262
Adercotryma aglerbergi	289
Haplophragmoides walteri	261
Dorothia seigliei	321
Reticulo. amplectens	29
Ammosph. pseudopauciloculata	32
Ammomarginulina aubertae	263
Haplophragmoides kirki	260
Reticulophragmoides jarvisi	291
Spiroplectammina spectabilis LO	68
Karreriella conversa	264
Reticulophragmium intermedia	175
Spiroplectammina navarroana	54
Subbotina patagonica	50
Coscinodiscus spp.	22
Cystammina pauciloculata	136
Trochamminoides coronatus	78
Rzehakina minima	105
Reticulophragmium paupera	76
Spiroplectammina spectabilis LCO	57
Saccammina placenta	310
Hormosina excelsa	134
Trochammina ruthven murrayi	129

Figure 19. Correlation of Well 6407/9-3 with the optimum sequence of Gradstein and Bäckström (1996). The numbers on the Y axis refer to a unique dictionary number for that species. The corresponding numbers on the X axis refer to the same species in this study.

The appearance of two or more numbers at the same column on the X axis means that the LOs were coincident in this study.

In general the plots show a good correlation apart from the LO of *Saccammina placenta* and the LO of *Spiroplectammina spectabilis* which plot consistently higher in the Halten Terrace wells. In both cases in the wells here, above the Paleocene their appearance is very sporadic and they are generally not well preserved. This may indicate that they have been reworked which would account for the differences seen. Those microfossil events that plot lower are probably due to only partial ranges being observed in the Halten Terrace wells and to caving. Well 6407/9-3 shows the most scatter in its points due to the large number of LOs that occur at one depth e.g. at one point seven species have an LO at the same level. Gradstein and Bäckström (1996) noted that in their Halten Bank wells the LO of *Karrerulina conversa* occurred within the Upper Palaeocene. However in the wells studied here the LO of *K. conversa* is found within the mid Eocene and therefore corresponds well with the optimum sequence.

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The differences between the optimum sequence and the order of LOs between individual wells are mainly due to the fact that within each wells LOs are often only local due to hiatuses, changing environmental conditions etc. whereas the optimum sequence, which is the composite result of many wells, minimises these effects.

4.6 Discussion

The zonal scheme of Gradstein *et al.* (1994) and Gradstein and Bäckström (1996) are similar to the findings in this study. The main differences occur in the ranges of some of the foraminifers and in their greater use of planktic foraminifers. This is doubtless due to the fact that their biostratigraphy is a composite one using data from both the Norwegian and North Seas, while this study concentrates on the Halten Terrace area.

Poole and Vorren (1993) also produced assemblage zones for the Miocene to Pleistocene using wells from an area slightly to the north of this one. Their findings are broadly similar to the ones here in that their assemblages were often dominated by *Melonis barleeanum* (their *Nonion barleeanum*) and *Cassidulina teretis*. They also observed a change from deep to shallow forms up section and their Lower Miocene to Upper Oligocene samples were heavily dominated by Radiolaria. Their Miocene assemblages however were generally more diverse and abundant than those observed here.

The work of Nagy *et al.* (in press), although from wells to the south of this area, has results similar to those in this study. They also report a low diversity area around the Paleocene/Eocene boundary and their Lower Eocene assemblages contain high abundances of *Spiroplectammina navarroana* and *Karrerulina* spp. However, they did not observe the influx of *Subbotina patagonica* and speculated that this was either due to the northern boundary of the species being south of the Barents Sea or that the bottom waters were too corrosive for calcareous microfossils to be preserved. They also reported the LCO of *Spiroplectammina spectabilis* to be in the middle Upper Paleocene rather than the Upper Paleocene as described here.

The scheme of Hulsbos *et al.* (1989) for the DSDP Site 338 is very different to the one devised here. In their Eocene sediments they often encountered quartz percentages of over 50%. They also found mainly calcareous faunas in the Eocene in stark contrast to the assemblages seen on the Halten Terrace. The differences can be accounted for by differences in palaeoenvironment. DSDP Site 338 lies on the outer part of the Vøring Plateau, which during the Eocene was probably at very shallow depths. Hulsbos *et al.*(1989) reported that during the earliest Eocene the site was at depths of between 50 and 200m, deepening slightly at the top of the Lower Eocene. This site would obviously lie above the local CCD enabling the production and preservation of calcareous tests. They also state that the foraminifers found were comparable to those from the Rockall Plateau at DSDP Site 117 and DSDP Sites 403-406 and that a marine connection between the Norwegian- Greenland Seas and the main North Atlantic Basin existed in the form of migration through the epicontinental seas of northern Europe

In contrast, ODP Site 643 on the slope of the Vøring Plateau was much deeper than the sites studied here. Kaminski *et al.* (1990) reported that the site was at mid bathyal depths in the Lower Eocene, lower bathyal depths in the Mid Eocene and by the Lower Oligocene was abyssal. The sites studied here, however, underwent a shallowing through time. One of the main differences to be noted is in the *Reticulophragmium amplectens* range. At OPD Site 643 it ranges into the Upper Oligocene while in the Halten Terrace area its LO is within the upper Mid Eocene. If *R. amplectens* is a 'deep' water species then this may be the explanation for its lower disappearance on the Halten Terrace. Kaminski *et al.* (1990) also state that their *Glomospira* spp. Assemblage represents the first appearance of Glomospira into the Norwegian Sea, and that *Karrerulina conversa* and *Trochamminoides* sp. all have FOs in this assemblage during the lower Middle Eocene. However in the Halten Terrace wells all these forms are also present in the Paleocene. Kaminski *et al.* (1990) also found the ranges of *Spirosigmoilinella compressa* and *Reticulophragmium amplectens* overlapping which does not happen in any of the wells studied here. In general many of the foraminifers observed in OPD Site 643 seem to range much higher than those from the Halten Terrace area.

Osterman and Spiegler's (1996) zonation for Site 913 in the Greenland basin is similar to those for the Halten Terrace, in that their Eocene assemblages were predominantly agglutinated and dominated by *Reticulophragmium amplectens*. They also found that Middle to Upper Eocene to Oligocene assemblages showed a drop in diversity and abundance. However, their most interesting result was that many of the foraminifers from Site 909 in the Fram Strait ranged into much younger strata than was expected. *Reticulophragmium amplectens* for example had its LO in Miocene sediments. Normally, this species has its acme occurrence in the Mid Eocene and its highest LO was reported by Kaminski *et al.*, (1990) to be in the Upper Oligocene. Osterman and Spiegler (1996) postulated that a deep-water, high sedimentation basin in the Fram Strait area, which remained isolated from the rest of the North Atlantic into the Miocene, was responsible for the anomalously long ranges of the foraminifers from Site 909.

The Pliocene and Quaternary foraminifers recorded in Fram Strait by Osterman (1996) were divided into four assemblages. The lower two assemblages *Cassidulina* spp. and *Elphidium* spp. indicated pre-glacial relatively warm environments, while the upper two assemblages, the *Elphidium albium-bilicatum* and *Elphidium excavatum* f. *clavata* indicated glacial/cold environments. The Pliocene assemblages are similar to those found in this study in that they contain large numbers of *Cassidulina* spp. However large numbers of *Melonis barleeanum* were not recorded at Site 910 and fewer *Trifarina* spp., *Fissurina* spp. or buliminids were recorded. Osterman (1996) also noted that although the LO of *Cibicides grossus* is usually taken as a Upper Pliocene/Quaternary marker, its well preserved appearance in Quaternary sediments means that caution should be taken when using this species to define the Pliocene/Quaternary boundary.

Seidenkrantz (1990) studied wells to the south of those studied here and concentrated on the Pliocene and Pleistocene. As in this study she found abundant calcareous assemblages again dominated by just a few species e.g. *Elphidium excavatum* forma *clavata* and *Cassidulina teretis*.

However she did not find the great numbers of *Melonis barleeanum* that appear to be typical for Norwegian shelf assemblages. She also recognised a *Textularia decrescens - Spiroplectammina deperdita* Zone in the Lower Pliocene which was not seen in the Halten Terrace.

During Phase 1 of this project (Steurbaut *et al.*, 1991), wells from the northern North Sea were also studied and samples were investigated from the whole of the Cenozoic. A pattern of agglutinated assemblages with large numbers of *Rhabdammina*-like tubes in the Paleocene and Mid to Upper Eocene (upper mid Ypresian - upper Rupelian) was observed. During the Lower Eocene (lower - mid Ypresian) assemblages with high numbers of planktic foraminifers were recorded. As in this study the agglutinated assemblages disappeared around the upper Mid Eocene to Lower Oligocene. In contrast to this work they found planktic-rich assemblages in the lower Upper Paleocene and abundant and diverse calcareous benthic assemblages from the Lower Oligocene onwards, such assemblages were not observed here.

King's (1989) zonal scheme is widely used in the North Sea. It can also be applied to some extent within the Norwegian shelf area. As can be seen from the assemblages devised for the Halten Terrace area there are very few calcareous benthics to be found in the Paleogene and lower Neogene so during this time only the NSA zones are applicable. During the Neogene some of the NSB and NSP zones can be used. Planktic foraminifers, however, are much rarer around the Halten Terrace than in the North Sea although some correspondence with Pliocene foraminifers has been found (Gradstein *et al.*, 1994; Gradstein and Bäckström, 1996).

Kaminski *et al.* (1989a) noted that in the Labrador Sea at ODP Site 647 the Paleogene assemblages are predominantly agglutinated and that there is a turnover of benthic foraminifers around the Eocene/Oligocene boundary from predominantly agglutinated assemblages to poor calcareous ones which is similar to the findings from the Halten Terrace although the assemblages at the Halten Terrace would seem to remain poor for much longer than those in the Labrador Sea. The change in assemblages at the Eocene/Oligocene boundary was related to changes in the preservation of agglutinated species and to the first appearance of cool, nutrient poor, deep water into the southern Labrador Sea. At the Ypresian/Lutetian boundary Kaminski *et al.* (1989a) reported a *Glomospira*-facies. Although a *Glomospira* Assemblage is also described here it would seem to occur somewhat later, in the upper mid Eocene, rather than at the lower/mid Eocene boundary.

Agglutinated assemblages were found in the Miocene at Site 646 (Kaminski *et al.,* 1989b). This is very different to the findings in this work where agglutinated foraminifers are observed to disappear much earlier around the Eocene/Oligocene boundary. The calcareous foraminiferal assemblages found in the Pliocene were also dissimilar (except for the presence of *Melonis barleeanum*) to those recorded here.

Figure 20 shows the approximate correlation between the biostratigraphy from this study and those most relevant to it.

Age	Gradstein & Bäckström '96	Poole &Vorren '93	Kaminski et al.'90	Nagy et al. (in press)	King 1989	This study
Pleist.	NSR13 *Cassidulina teretis*	Zone IVe			NSB16	*Cibicides grossa*
L. Plio.	NSR12 *Cibicidoides grossa*	Zone IVa-d			NSB15	*Elph. excavatum f. clavatum* / *Melonis barleeanum*
		Zone III			NSB14	*Cassidulina teretis*
E.Plio.	NSR11 *Neoglob. atlantica*	Zone IId				*S. bulloides*
		Zone IIc			NSB13	
L.Mio.	*Bolboforma metzmacheri* NSR10	Zone IIb			NSA12	*Bolboforma metzmacheri*
	Martiniotiella cylindrica NSR9B				NSB11 - NSB12	
M.Mio.	NSR9A *Globorotalia ex. gr. praescitula zealandica*	Zone IIa			NSA11	*M. communis* / *Bolboforma spp.*
					NSB10	
E Mio.	Not Zoned	Zone I	*Psamminopelta sp.*		NSA10 NSB9	Unzoned Interval
					NSA9 NSB8	
L. Olig.			*Psamminopelta sp.*		NSA8	
			R. amplectens			
E.Olig.	NSR7B *Turrilina alsatica*				NSA7 NSB7	*Turrilina alsatica* / *S. compressa*
NSR7A	*Adercot.. agterbergi*		*Spirosigmoilinella compressa*		NSA6 NSB6	
L.Eo.	Hiatus					Hiatus
M.Eo.	NSR6A *Reticulophragmium amplectens*				NSB5	*G. charoides*
	NSR5B *Ammomarginulina aubertae*		*Glomospira spp.*		NSA5	*R. amplectens*
	NSR5A *Reticuluphragmium intermedia*					
E.Eo.	NSR4 *Subbotina patagonica*			*Reticulophragmium amplectens*	NSA4 NSB4	*Karreriella spp.* / *S. navarroana*
			Rhabdammina		NSA3 NSB3	*Subbotina patagonica*
	NSR3 *Coscinodiscus spp.*		*Cyclammina*	*Spiroplectammina navarroana*	NSA2 NSB2	*Coscinodiscus spp.*
	NSR2B *Reticulophragmium paupera*			*Haplo. aff. eggeri*	NSA1	Impoverished
L.Palc.				*R. paupera*		*Trochammina ruthven-murrayi*
	NSR2A *Trochammina ruthven-murrayi*			*Spirop. spectabilis*		*S. spectabilis*
E. Palc	Hiatus			*Psammosph. fusca*	NSB1	Hiatus

Note: "Nonion barleeanum" labelled vertically within the Poole & Vorren '93 column (Zone IIa–IId).

Legend: ▨ Hiatus ◩ Hiatuses common ☐ Not studied

Figure 20. Approximate correlation of Halten Terrace biostratigraphy to other relevant biostratigraphies.

5. Palaeoenvironmental analysis

5.1 Introduction

Palaeoenvironmental interpretations are based on changes within foraminiferal morphogroups and in other microfossil groups. Within each section a discussion of the results for each well is given. Palaeoecology for the region is then discussed and a summary of the palaeoenvironments in the Halten Terrace area is presented. Total Organic Carbon (TOC) values are from Aichinger (in prep.).

5.2 Previous work

Recent benthic foraminifers are known to live in a wide range of microhabitats from epiphytal to deep infaunal, shallow to deep water and hypo- to hypersaline. Their distribution is controlled by a number of parameters such as nutrient supply, salinity, temperature, substrate, depth of the CCD and oxygen and CO_2 content of oceanic bottom water masses, the sediment/water interface and within surficial sediments.

A large number of studies have investigated the relationship of one or more of the above parameters to benthic foraminiferal distribution. Pflum and Frerichs (1976) and Culver (1988) studied changes with depth, while Streeter (1973), Schnitker (1974, 1979) and Lohmann (1978) studied the relationship between various water masses and foraminiferal assemblages. Sejrup et al. (1981) and Austin and Sejrup (1994) investigated the relationship between oceanographic conditions and foraminiferal distribution along the Norwegian continental margin and from fjords in western Norway. Almogi-Labin et al. (1996) reported agglutinated foraminifers response to glacial/interglacial cycles and changes in salinity and oxygen conditions in the Red Sea.

Some culture studies have been carried out on benthic foraminifers to determine their movement patterns and preferences in response to food supply and sedimentation events (Lutze and Altenbach 1988; Kitazato 1988, 1989; Linke et al., 1995; Bornmalm et al., 1997). Bernhard (1993) reported that certain benthic foraminifers could survive for up to 30 days in anoxic conditions. Loubere et al. (1995) reported that some foraminifers live in association with larger organisms and do not have strict habitation depths and referred to microenvironments created by animals larger than the foraminifers. Bornmalm et al. (1997) investigated agglutinated and calcareous foraminifers under laboratory conditions and found that the species studied moved both within and out of the sediment.

Bernhard (1986), Altenbach and Sarnthein (1989) and Goody and Turley (1990) noted that high productivity areas were characterised by specific assemblages. The relationship to carbon flux has been the subject of a number of papers (Miller and Lohmann, 1982; Lutze and Colbourn 1984; Boersma 1985; Mackensen et al., 1985; Corliss and Chen, 1988; Caralp, 1989; Corliss and Emmerson 1990; Corliss 1991; Loubere et al., 1993). Miller and Katz (1987) concluded that changes within benthic foraminiferal assemblages from the Oligocene to Miocene in the North Atlantic were primarily connected with changes in primary productivity and Thomas et al. (1995) stated that changes in deep sea benthic foraminiferal communities over the past 45,000yrs in the NW Atlantic

were the result of surface water productivity changes. Recently, Loubere (1996) showed that abundance patterns of foraminifers were strongly influenced by a response to surface ocean productivity. Therefore, it is probable that the flux of organic matter is a primary control on foraminifers.

There is much debate over whether changes in assemblages arise from increased nutrient availability or lowered oxygen levels or a combination of these parameters. These factors are often not separable and a high organic input may result in dysoxic bottom conditions (Jorrissen et al., 1992). Sjoerdsma and van der Zwaan (1992) also concluded that most important factor affecting the distribution of foraminifers was the interplay between organic flux and oxygen levels. At greater depth, although oxygen levels may be high, nutrient input is often low and becomes the limiting factor (Corliss and Emerson, 1990).

A number of studies have related test morphology or morphogroups to life position. Severin (1983), Corliss (1985), Corliss and Chen (1988), Corliss and Fois (1991) and Corliss (1991) studied mainly calcareous benthics from the Recent or Quaternary. Jones and Charnock (1988) studied mainly Recent agglutinated foraminifers and proposed using similar morphogroups for past environments. Jones (1980) carried out similar work on agglutinated morphotypes from the Paleogene from the Viking Graben. Bernhard (1986) studied both calcareous and agglutinated foraminiferal assemblages from the Jurassic to Holocene that were characteristic of anoxic, organic rich deposits and Nagy (1992), Nagy et al. (1995) and Nagy et al. (in press) have used the morphogroup concept for Jurassic, Cretaceous and Paleogene foraminifers from the North Sea, Nepal and the Barents Sea. Each morphogroup consisted of foraminifers of similar morphotypes based on test shape, mode of coiling, presence/absence of surface pores etc. which were presumed to share similar feeding and movement strategies and life positions. In this way the change of morphogroups - which reflected the changes in microhabitat - through time could give useful information about changing environmental conditions. Within many of these works, however, there is often the assumption of a rather static partitioning of the environment with foraminifers being almost exclusively infaunal or epifaunal and/or confined to specific depths within the sediment.

Recent works (Corliss and Emerson, 1990; Barmawidjaja, 1992; Jorissen et al., 1992; Linke and Lutze, 1993; Buzas et al., 1993) have shown that this probably is not the case and that life position is very much dependent on nutrient supply and oxygen content of the bottom and interstitial waters. It was found that many foraminifers previously labelled infaunal could live at the surface when oxygen levels were low and many epifaunal forms could also be found infaunally and that habitat could vary seasonally depending on the nutrient supply and conditions. Kaiho (1994) reported changes in microhabitat and test thickness and porosity in response to changes in oxygen concentration while Sen Gupta and Machain-Castillo (1993) stated that those foraminifers found in dysoxic-suboxic conditions are not characterised by any one particular test morphology. Kuhnt et al. (1996) studied deep water agglutinated foraminifers (DWAF) from the Recent and related their findings to fossil agglutinated communities. They recognised that foraminiferal diversity and

abundance were strongly controlled by organic flux which influences the redox boundary and oxygen content of bottom waters. A continuous spectrum of environments was recognised with two end member communities, those from oligotrophic environments and those from eutrophic environments.

A useful division of microhabitat is that of Barmawidjaja *et al.* (1992) who divided Recent foraminifers from the Adriatic into three main groups:

1. Epifaunal - almost exclusively in the top few centimetres of sediment
2. Predominantly infaunal and
3. Potentially inbenthic - showed epi- or infaunal characteristics depending on oxygen content of waters.
Foraminifers that were exclusively infaunal were not found in this study.

It seems likely that a dynamic idea of microhabitat in which foraminifers move within the sediment and change in relative abundance in response to nutrient/oxygen levels is more useful than a static approach and reflects more accurately the real situation with regard to the life position of foraminifers.

5.3 Morphogroup analysis

For this study a morphogroup scheme was devised using the above information to help in the interpretation of palaeoenvironments. The assemblages recorded in the Paleocene and Eocene may be secondary dissolution assemblages, which leads to the question of whether such assemblages can be used for palaeoecological/environmental interpretations. Recently Alve and Murray (1995) investigated the validity of using acid treated assemblages (ATAs), i.e. assemblages in which the calcareous component was dissolved away, in palaeoecological studies and found, somewhat surprisingly, that these secondary assemblages showed good agreement in diversity with their parent assemblages. They concluded therefore that it was quite feasible to use such ATAs for inferring palaeoecology.

For the Halten Terrace wells, the morphogroups shown below for the calcareous and agglutinated foraminifers were recognised. In the following sections the changes within the biogenic components and then within the morphogroups are discussed.

5.3.1 Agglutinated morphogroups:

1. Tubes: contains all the tubular genera e.g. *Bathysiphon, Rhabdammina, Rhizammina*. These are probably epifaunal suspension to detritovore feeders.

2. Ammodiscids: foraminifers from the genera *Ammodiscus* and *Glomospira*, epifaunal to shallow infaunal active deposit and detrital feeders.

3. Planispiral/lenticular: active herbivores and omnivores. Contains *Cyclammina* and *Haplophragmoides.*

4. Globular/streptospiral: epifaunal/shallow infaunal deposit feeders. Mainly *Recurvoides* and *Saccammina.*

5. Planoconvex: predominantly epifaunal to shallow infaunal herbivores and detritovores. Mainly *Trochammina* spp.

6. Elongate/tapered: predominantly infaunal detritovores from the genera *Reophax, Karrerulina* and *Spiroplectammina.*

5.3.2 Calcareous foraminiferal morphogroups

1. Globular/ovoid: live in or near the sediment surface, predominantly infaunal, consists mainly of species from the genera *Fissurina* and *Oolina.*

2. Trochospiral/milioline: epifaunal to shallow elevated, species of the genera *Cibicides, Gyroidina* and *Miliolina.*

3. Planispiral/lenticular: motile i.e. move within and on top of the sediment, mainly species from the genera *Elphidium, Cassidulina, Melonis* and *Lenticulina.*

4. Elongated/tapered: predominantly infaunal morphotypes, species of *Bulimina, Uvigerina* and *Trifarina.*

5.4 Well 6406/8-1

5.4.1 Biogenic components

As can be seen from Fig. 21 agglutinated foraminifers are the dominant biogenic component from the base of the studied section (2800m) to around 2410m where they start to decrease in abundance. After this point their abundance and diversity remain at extremely low values. In contrast, the calcareous foraminifers show a very different pattern. In the lower part of the well they are rarely, if ever, seen. The calcareous benthics encountered at these depths are often caved and/or very badly preserved, having an almost 'melted' appearance. From about 1580m calcareous benthics are seen but usually in very low numbers. Two exceptions are at 1560m where they make up just over 9% of the total assemblage (absolute number = 74) and at 1380m where nearly 500 foraminifers are found making up >90% of the total assemblage. Planktic foraminifers are very rare throughout the whole section and never make up much more than 1% of the total assemblage.

Of the siliceous microfossils radiolarians are the most abundant. They first appear in high numbers at 2180m and in general dominate the assemblages above this point until they start to decrease in
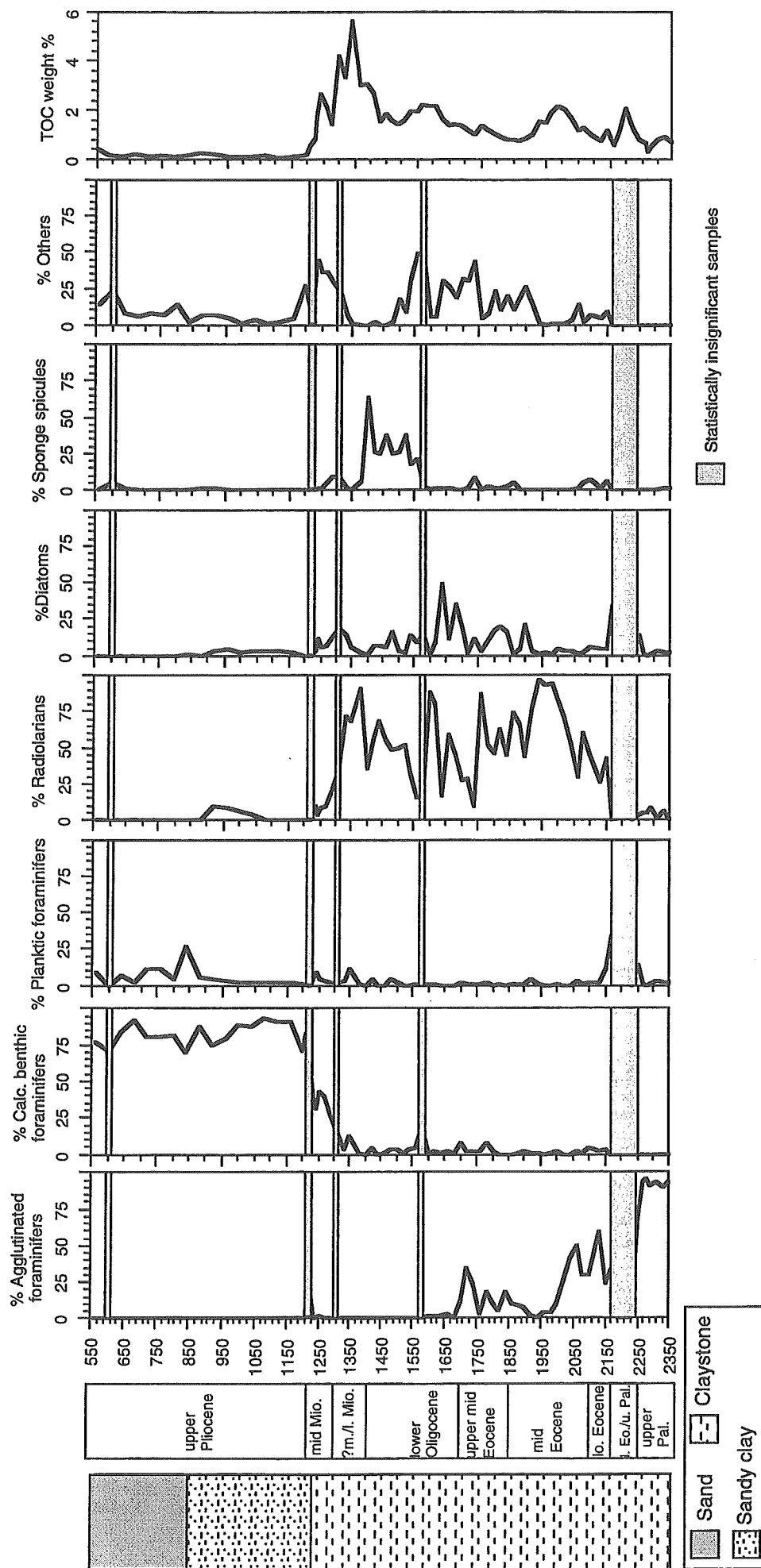
Fig. 21. Well 6406/8-1 distribution of biogenic components
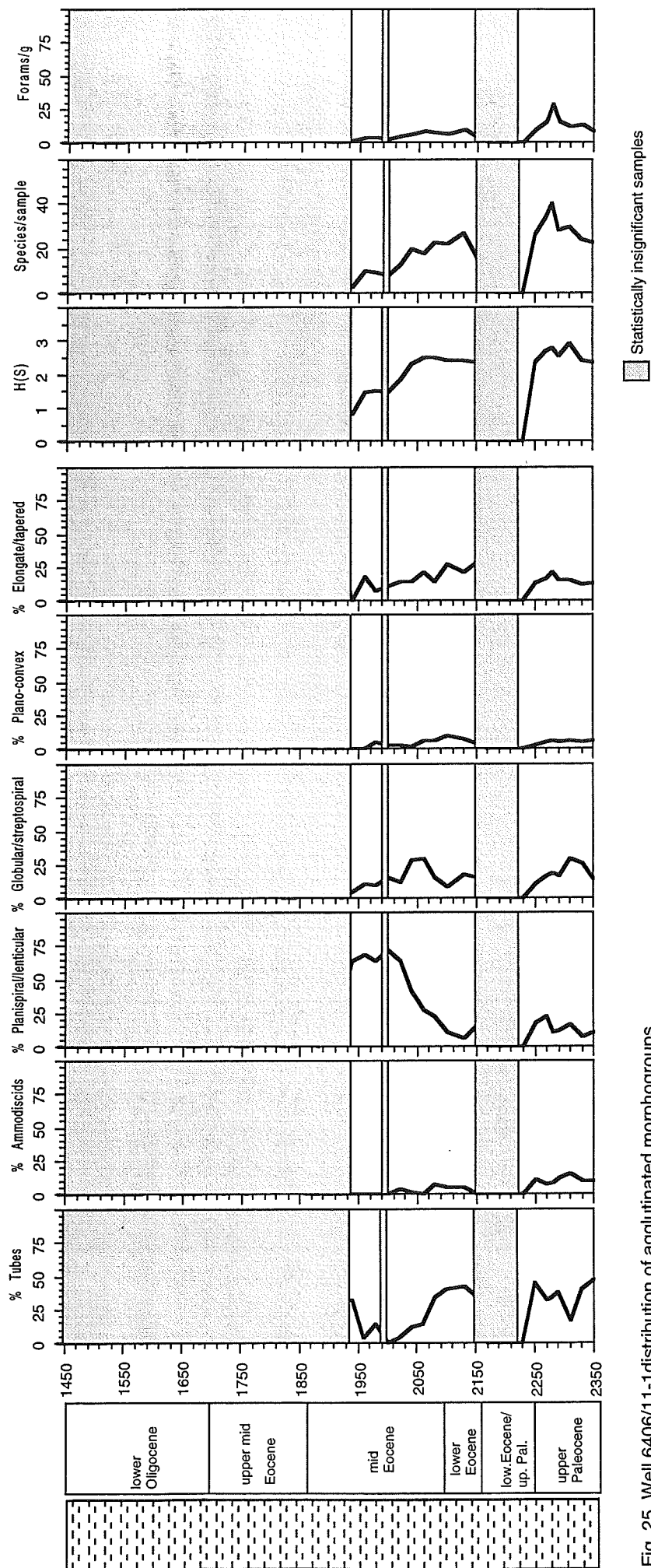
64
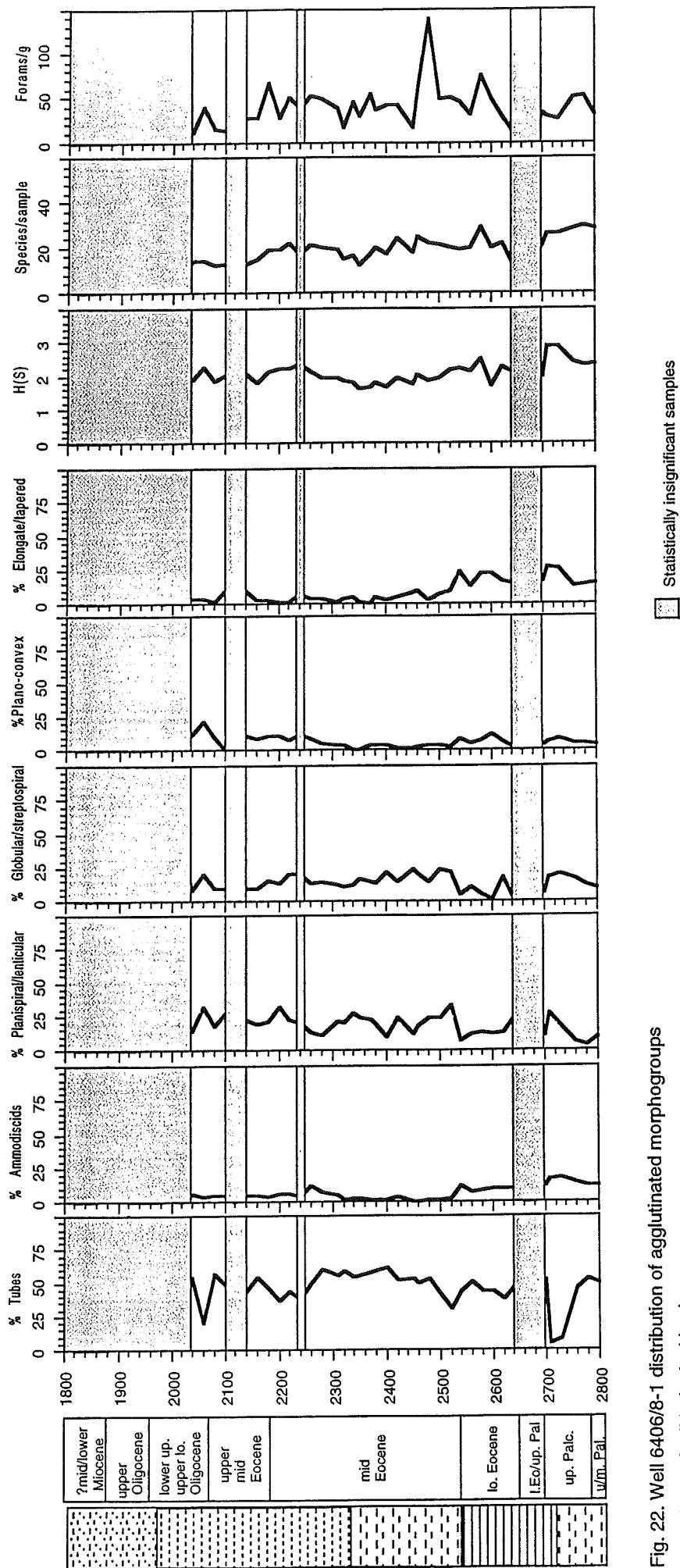
Fig. 22. Well 6406/8-1 distribution of agglutinated morphogroups (see Fig. 21 for lithological key)
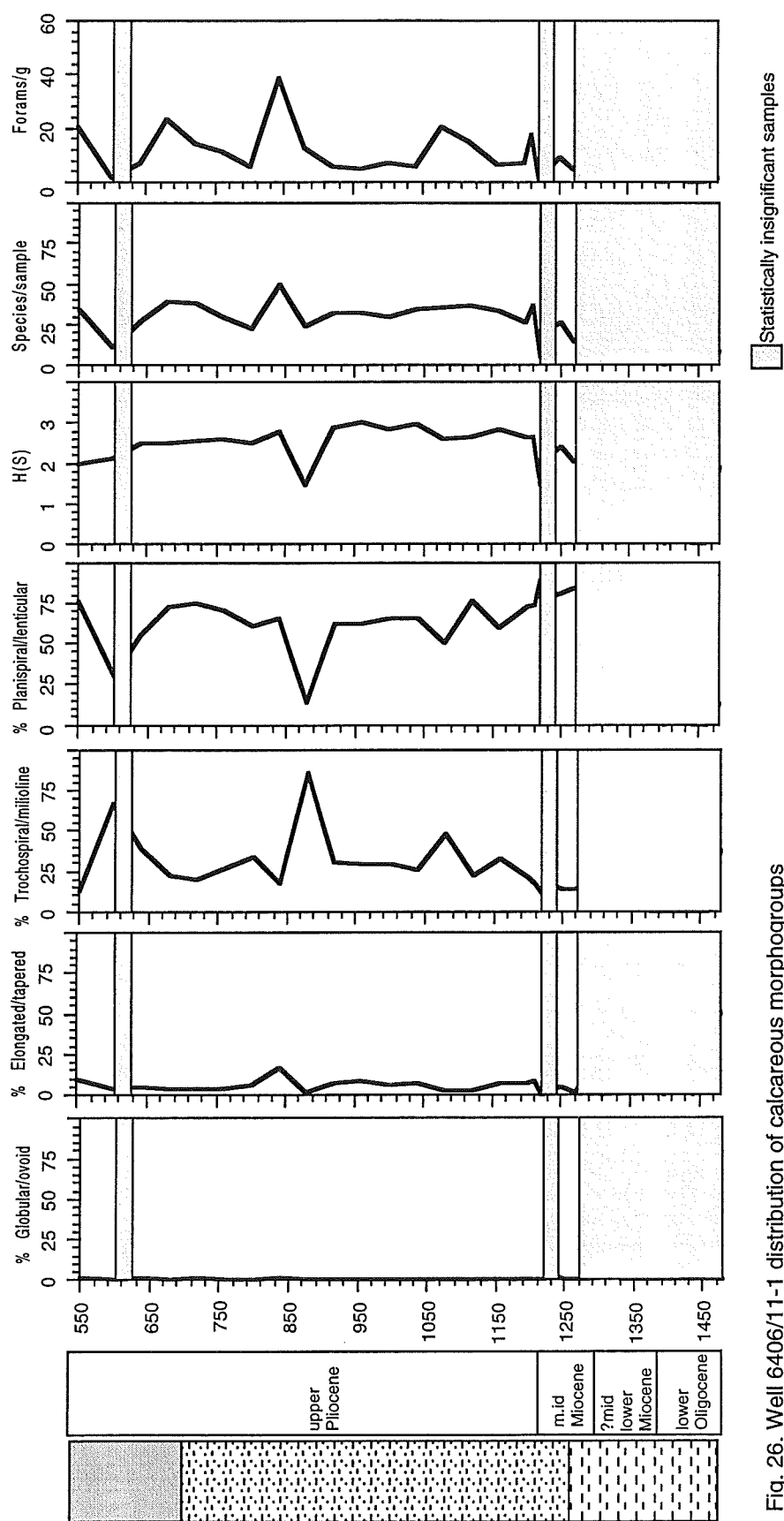
65

Fig. 23. Well 6406/8-1 distribution of calcareous morphogroups

(see Fig. 21 for lithological key)

☐ Statistically insignificant samples

66
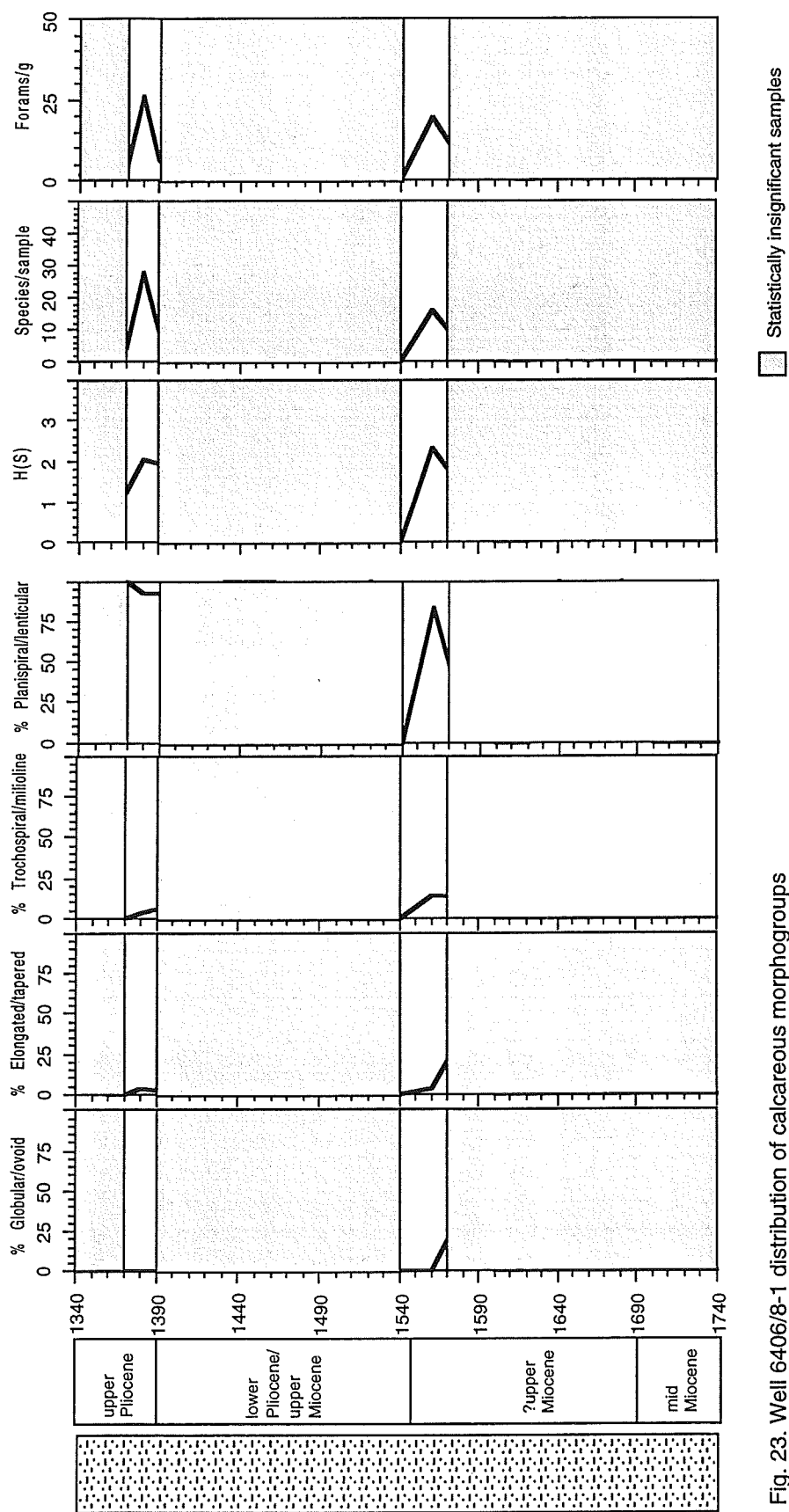
abundance at around 1720m. They are most common in two main areas; around 2040m to 2140m and between 1860m to 1740m. Diatoms are generally rare throughout the section. A few peaks are seen but it is uncertain as to whether they are statistically useful as they occur in areas where there are less than 100 components in total. However the peak around 2620m-2640m does contain stratigraphically useful diatoms. Sponge spicules and fragments are unimportant throughout the whole section studied. The group 'Others' contains ostracods, echinoid spines, bolboforms and pyritized burrows/worm tubes. In all cases the peaks seen in Fig. 21 are caused by high numbers of these pyritized burrows. Not included in the counts are shell fragments (e.g. from bivalves and gastropods). which appear in extremely high numbers above 1380m.

5.4.2 Agglutinated morphogroups

At the base of the well to 2780m the assemblages are dominated by tubular forms (around 40-50%) e.g. *Rhabdammina, Bathysiphon* etc. As the numbers of tubes decreases from 2780m to 2710m there is an increase in the other agglutinated morphogroups and an increase in H(S) values although there is a fall in abundance. Above the short barren /impoverished interval there is a return to assemblages dominated by tubular forms. Above 2600m the assemblages are dominated by tubular forms except at 2520m where they show a slight drop in abundance. This is due to the high abundance of *R. amplectens* at this depth. However, unlike the other three wells *R. amplectens* is not overwhelmingly dominant during the mid Eocene. The elongated/tapered and ammodiscid groups have relatively low abundance throughout, except at the bottom of the section from 2720m to 2520m where the elongate group especially has abundance values as high if not higher than the other groups apart from the tubes. Throughout the section H(S) values remain relatively high. A number of peaks in the grain size analysis seem to correspond to peaks in foraminiferal abundance (see Fig. 22) In general at these points diversity also shows a decrease although it could be considered that the small size of the samples (sometimes less than 5g) may give unrepresentative values.

5.4.3 Calcareous morphogroups

The number of calcareous benthics found in Well 6406/8-1 (see Fig. 23) are extremely low - usually less than 50 per sample. Two exceptions are at 1380m and 1560m where 452 and 74 foraminifers respectively were observed. When present, the planispiral/lenticular forms are dominant, and consist mainly of the *Melonis barleeanum* and *Cassidulina teretis*. The elongate/tapered group also appears briefly at 1380m and consists of buliminids.

5.4.4 Summary

In the lower part of the section, H(S) values remain at a relatively high level (>2). it is therefore likely that the environment was a relatively stable one with a wide variety of ecological niches. The abundance of *Rhabdammina* and *Bathysiphon* tubes in the lower part of the section point to relatively deep water conditions with at least some current activity and a regular nutrient supply as these tubular forms are probably suspension feeders Jones (1988). The change at 2780m where the

tubular group decreases dramatically may be due to vigorous circulation, which condition does not favour tubular foraminifers. The groups that are most diverse at this time are the two probably infaunal groups and the planispiral group which may be more adaptable to such conditions. As in the other three wells *S. spectabilis* is very abundant and again no calcareous benthics are recorded which suggests a deep environment at or near the lysocline. The elongate forms and ammodiscids increase slightly above the barren interval. This may point to slightly adverse conditions as the ammodiscids are generally thought to be opportunistic types able to live in a variety of conditions. The elongate forms may also be mainly infaunal and, therefore, better adapted to dealing with mildly dysoxic conditions at or below the sea floor. However, since no great changes within the agglutinated morphogroups can be recognised until a big influx of radiolarians occurs, it appears that conditions were relatively uniform. The lack of calcareous foraminifers suggests a deep water environment below the CCD. The change at around 2180m is quite dramatic with a loss of agglutinated foraminifers and a sudden dominance by siliceous microfossils. This large increase in silica flux to the sea floor may have the effect of increasing the pH of the waters and therefore creating unfavourable conditions for benthic life. This lowering of pH would also have increased the dissolution of calcareous tests. Therefore the agglutinated assemblages seen may partly be an artefact of the prevailing environment and actually be dissolution assemblages. The increase in biosiliceous sedimentation is accompanied by a rise in TOC values, which suggests dysoxic bottom conditions.

The calcareous assemblages are very low in abundance and do not have a continuous appearance as in the other wells. This may be due to loss by erosion as when taxa do occur they are, in general, abundant and well preserved. The H(S) values at these points are also high, which point to conditions being favourable for benthic life. However, apart from the two dominant species *Melonis barleeanum* and *Cassidulina teretis*, other taxa are present in very low numbers. Both of these species are indicative of relatively deep water and are thought to be motile i.e. able to live within ,and on the sediment surface. This, together with their extremely high abundance, points to the exploitation of the environment by a few opportunistic species.

5.5 Well 6406/11-1

5.5.1 Biogenic components

Fig. 24 shows the distribution of the biogenic components found in Well 6406/11-1. Among the foraminifers the agglutinated benthics are the most abundant group in the lower part of the section. From 2350m to the base of a barren zone they are extremely abundant and are the dominant microfossils - over 90% of the total assemblage. Above the barren zone they recover in abundance but not to the same values as before. Two peaks are observed at 2060m and 2130m after which there is a gradual decline to practically no agglutinated foraminifers between 1920m and 1940m. They then recover for a while before disappearing at around 1700m. The calcareous benthics are rarely

Fig. 24. Well 6406/11-1 distribution of biogenic components

69

Fig. 25. Well 6406/11-1 distribution of agglutinated morphogroups
(see Fig. 24 for lithological key)

Statistically insignificant samples

70

Fig. 26. Well 6406/11-1 distribution of calcareous morphogroups
(see Fig. 24 for lithological key)

Statistically insignificant samples

71

seen in the lower part of the well but start to appear in significant numbers at around 1270m. Throughout the top part of the section (1270m-560m) they are the dominant microfossils. Planktic foraminifers are only occasionally present, at 2150m and 2250m and near top of the section at 840m where they make up ca. 27% of the total assemblage.

Among the siliceous microfossils radiolarians are dominant. They start to appear in great numbers at around 1980m. Above this depth they are the dominant microfossils until they start to decline in abundance at 1330m. They appear in three main pulses from 1980m to 1760m, 1660m to 1600m and 1520m to 1380m. Diatoms occur in the lower part of the well and have peaks of ca. 20% around 1900m and 1820m and of over 30% at 1640m and 1680m. Sponge spicules and fragments have a peak between 1400m and 1560m.

The group 'Others' consists of ostracods, echinoid spines, bolboforms and pyritized burrows/worm tubes. In all cases the peaks seen in Fig. 24 correspond to a high abundance of these burrows. Shell fragments e.g. from bivalves and gastropods are also an important part of the biogenic components. They have not been included in the counts, however, as they are only ever seen as small fragments and it is impossible to estimate the real number of bivalves etc. represented. They are very prominent from 1210m to the top of the well

5.5.2 Agglutinated morphogroups

At the base of the section diversity is high with H(S) values of over 2 seen throughout the section from 2350m to 2250m. Abundance is also quite high with a peak at 2280m of just over 28 foraminifers/g. Tubular forms are the most dominant forms except at 2310m where the globular/streptospiral group is slightly more numerous. In general, throughout this section there is a good spread between all the main morphogroups. From 2230m to 2170m there is an interval that is completely devoid of foraminifers with the siliceous microfossils also present in only very low numbers. Above the barren interval there is a return to a diverse assemblage with an initial increase in the number of elongated/tapered forms. Tubular foraminifers again represent the dominant morphogroup. Abundance is lower above the barren zone than below it. A decline in the tubular group starting at about 2080m is accompanied by a big increase in the planispiral/lenticular morphogroup and a drop in diversity to H(S) values of less than two by 2020m. This decline in diversity continues throughout the top part of the section to 1860m where agglutinated foraminifers are extremely rare (Fig. 25).

5.5.3 Calcareous morphogroups

Fig. 26 shows the distribution of calcareous morphogroups. As can be seen the planispiral/lenticular group and the trochospiral/milioline groups are dominant and would seem to be almost mutually exclusive. The other two groups, elongate/tapered and globular/ovoid, are present only rarely. However, within the globular/ovoid group species of *Fissurina, Oolina* and buliminids form a useful stratigraphic correlation point, being found in three of the four wells studied.

5.5.4 Summary

The foraminifers between 2235m and 2250m together with the high H(S) values (>2) indicate a well partitioned environment with no particular adverse conditions. The presence of large numbers of *Rhabdammina* and *Bathysiphon* type tubes and a high abundance of *Recurvoides* spp. points to an environment with at least some current activity as these foraminifers today are known to prefer such conditions (Jones 1988). Abundant *S. spectabilis,* together with the robust, thick *Rhabdammina* and *Bathysiphon* type tubes are typical for middle bathyal/slope depths (Gradstein and Bäckström, 1996; Jones, 1988). The occasional presence of deep water forms such as *Paratrochamminoides* spp., *Recurvoides* spp. *Cystammina* spp. and *Labrospira* spp. (Kuhnt *et al.,* 1989) suggests that during this interval the location was probably at mid to lower bathyal depths.

Just above the barren zone there is an increase in the percentage of elongate/tapered forms. If, as has been postulated, these types are mainly infaunal (Jones and Charnock, 1988) they may be better suited to slightly dysoxic bottom conditions. Tubular forms are then again dominant signalling a return to more equitable quiescent conditions probably below the CCD as no calcareous benthics are seen and *S. spectabilis,* a calcareous cemented form, is only rarely seen. *Reticulophragmium amplectens* then starts to dominate the assemblages. This foraminifer may be opportunistic and highly adaptable as it begins to dominate when radiolarians start to increase in abundance. Above 2000m the tubular forms change to more branching, thinner *Rhizammina* type tubes. Jones (1988) suggested that these have a preference for fine grained, low energy, deep environments. This is also supported by the increasing abundance of radiolarians indicating highly productive surface waters with a heavy biosiliceous input to the sea floor that is not removed by currents. Towards the top of the section the decrease in H(S) values indicates a steady decrease in the diversity as the environment becomes increasingly unfavourable for benthic foraminifers. The disappearance of the agglutinated foraminifers may also be connected with a gradual shallowing of the shelf area through the Eocene and Oligocene (Stuevold and Eldholm, 1996). However, calcareous foraminifers are still only rarely recorded during this interval probably due to dissolution through the low pH of the waters at this time caused by increased biosiliceous input.

The siliceous microfossils are dominant until the upper Pliocene. The dominance of radiolarians occurs together with a large increase in TOC values indicating that subsurface conditions may have been slightly dysoxic. This would also have contributed to the very impoverished assemblages with very few calcareous benthics observed.

The decline in the siliceous groups is matched by an increase in calcareous foraminifers. Their abrupt and abundant appearance of upper Pliocene foraminifers indicates that a hiatus is probably present through much of the upper Miocene to lower Pliocene. The dominance by two groups which are mainly epifaunal/motile i.e. the planispiral/lenticular and trochospiral/milioline groups and the rare occurrence of the two groups presumed to be infaunal i.e. elongated/tapered and globular/ovoid and the greatly reduced TOC values may point either to an environment in which there was reduced nutrient flux to the sea floor or to the fact that the more motile groups were more easily able to cope

with the extremely high sedimentation rates, which themselves may have had the effect of diluting nutrient input to the sea floor. From 1200m to the top of the studied section there are increasing numbers of shallow and cold water foraminifers are recorded e.g. *Quinqueloculina seminulum, Buccella frigida, Elphidium incertum* and *Elphidium excavatum* f *clavata.*

5.6 Well 6407/7-2

5.6.1 Biogenic components

The distribution of biogenic components within well 6407/7-2 is shown in Fig. 27. In the lower part of the section from 2000m to 1590m agglutinated foraminifers are the dominant microfossils often having an abundance of over 90% of the total assemblage. Above 1590m they decline rapidly in abundance and are rare, at 1210m they disappear. Calcareous foraminifers are not really seen in significant numbers in the lower part of the well. They appear suddenly in great abundance at 1050m and are the dominant microfossils thereafter. Planktic foraminifers are extremely rare throughout the whole section studied.

Radiolarians are again the dominant siliceous fossil seen and start to appear in high numbers at around 1610m. This event occurs at the same time as agglutinated foraminifers become extremely rare. Until 1210m radiolarians dominate the biogenic assemblages, at which point they show a sudden decrease and disappear above 1080m. Diatoms have only one small stratigraphically useful peak between 1760m and 1720m. The groups sponge spicules and 'Others' do appear, but only in low numbers and in areas where there are very few biogenic components in general i.e. less than 100. Not included in these counts, due to their fragmentary nature, but present in high numbers above 1070m are shell fragments of bivalves and gastropods.

5.6.2 Agglutinated morphogroups

As can be seen from Fig. 28 the tubular morphogroup is in general the dominant group up to the impoverished area with one 'dip' at 1950m which corresponds to an increase in the other morphogroups. Shortly above the barren interval there is a sudden increase in the elongated/tapered morphogroups between 1710m and 1650m. The tubular group also shows an increase during this period while the planispiral and globular groups show a large decrease in abundance. Above this from 1650m to 1530m there is a large increase in the latter two groups which is connected with a large decrease in the tubular group.

H(S) value remain quite high (greater than 2) up to 1650m above which there is a sharp drop in diversity. This is also connected with an increase in the planispiral group. Abundance remains quite steady throughout the section (apart from the barren area) until 1570m when there is a sharp drop.
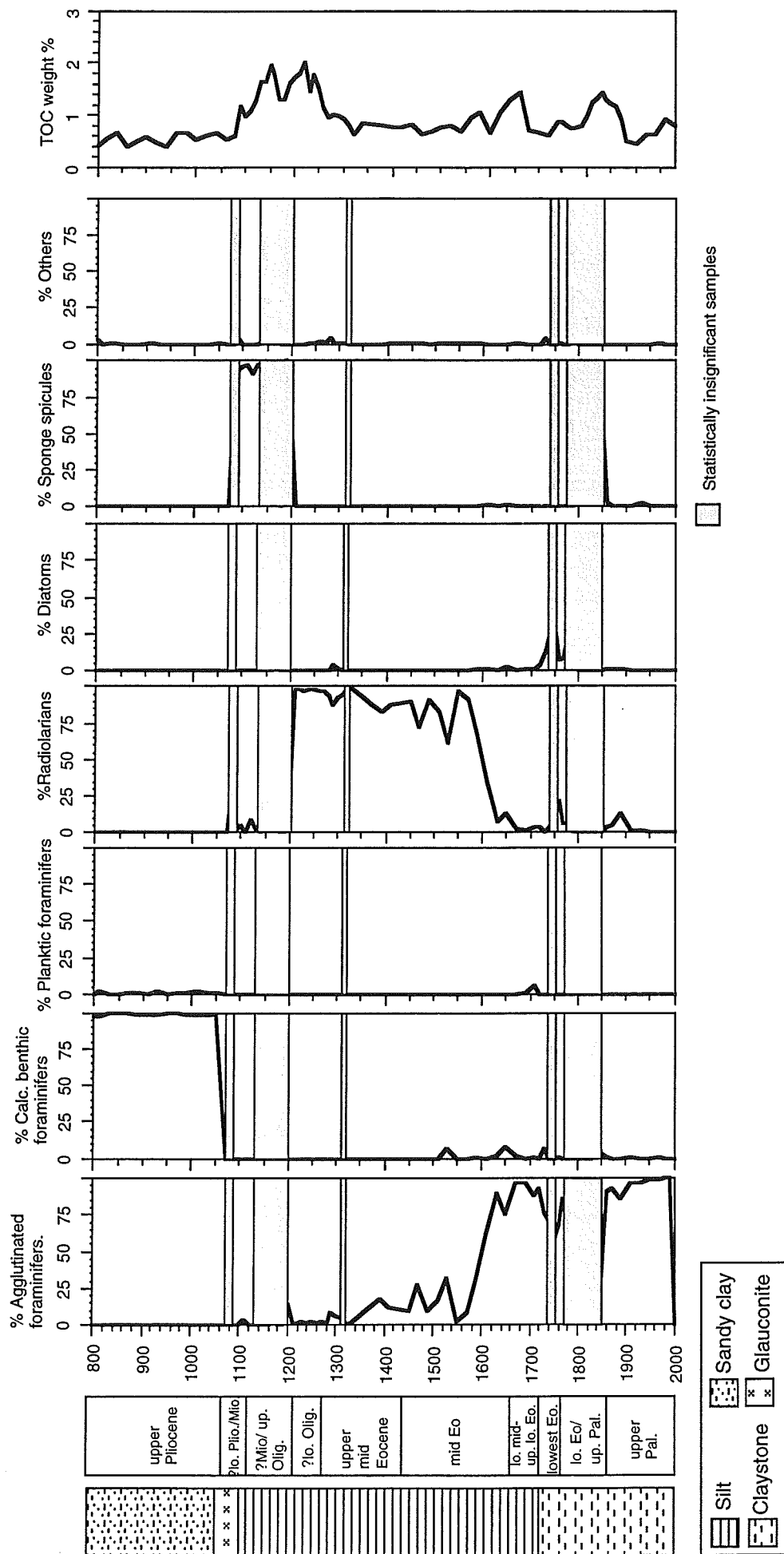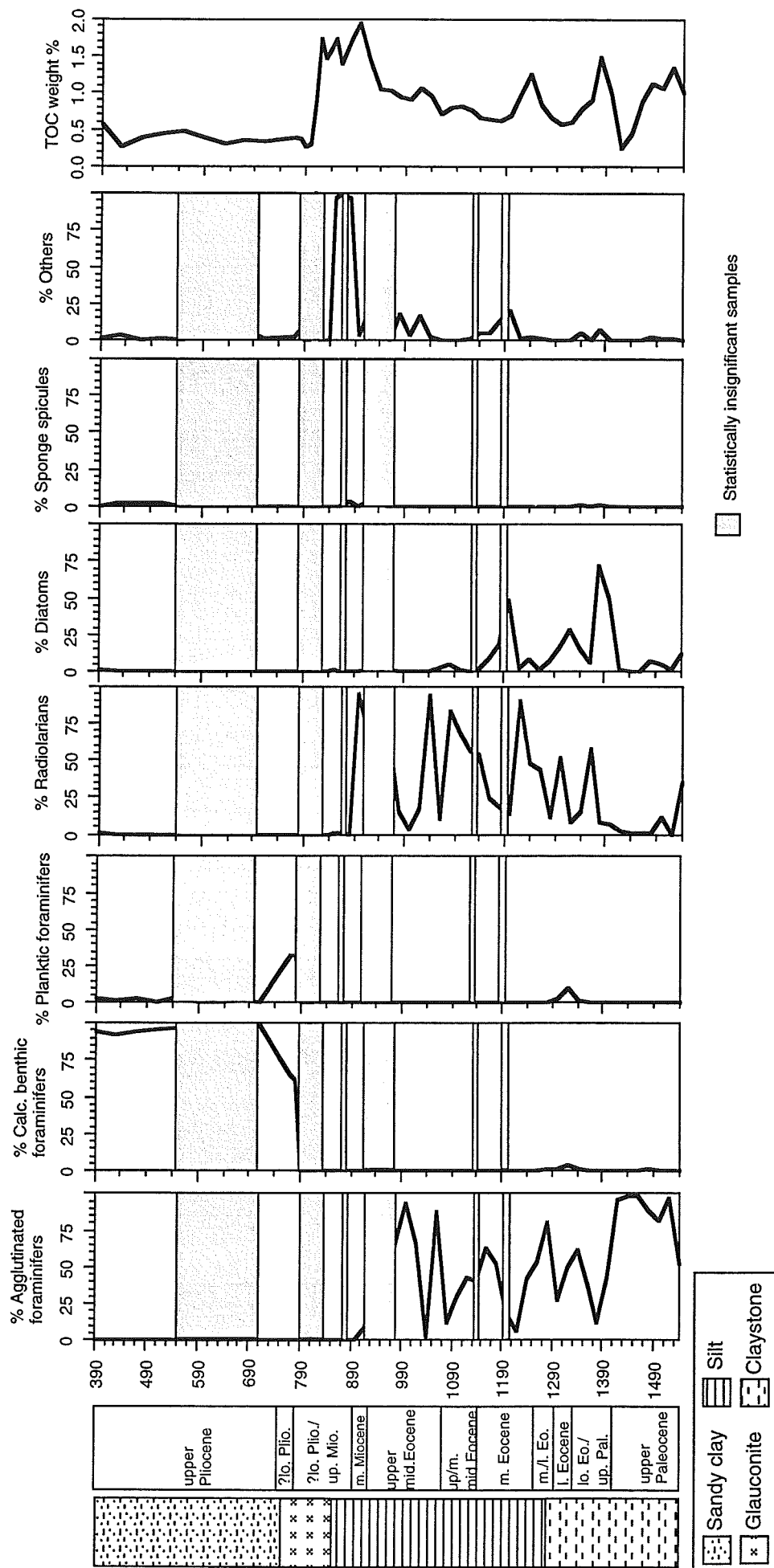
Fig. 27. 6407/7-2 distribution of biogenic components
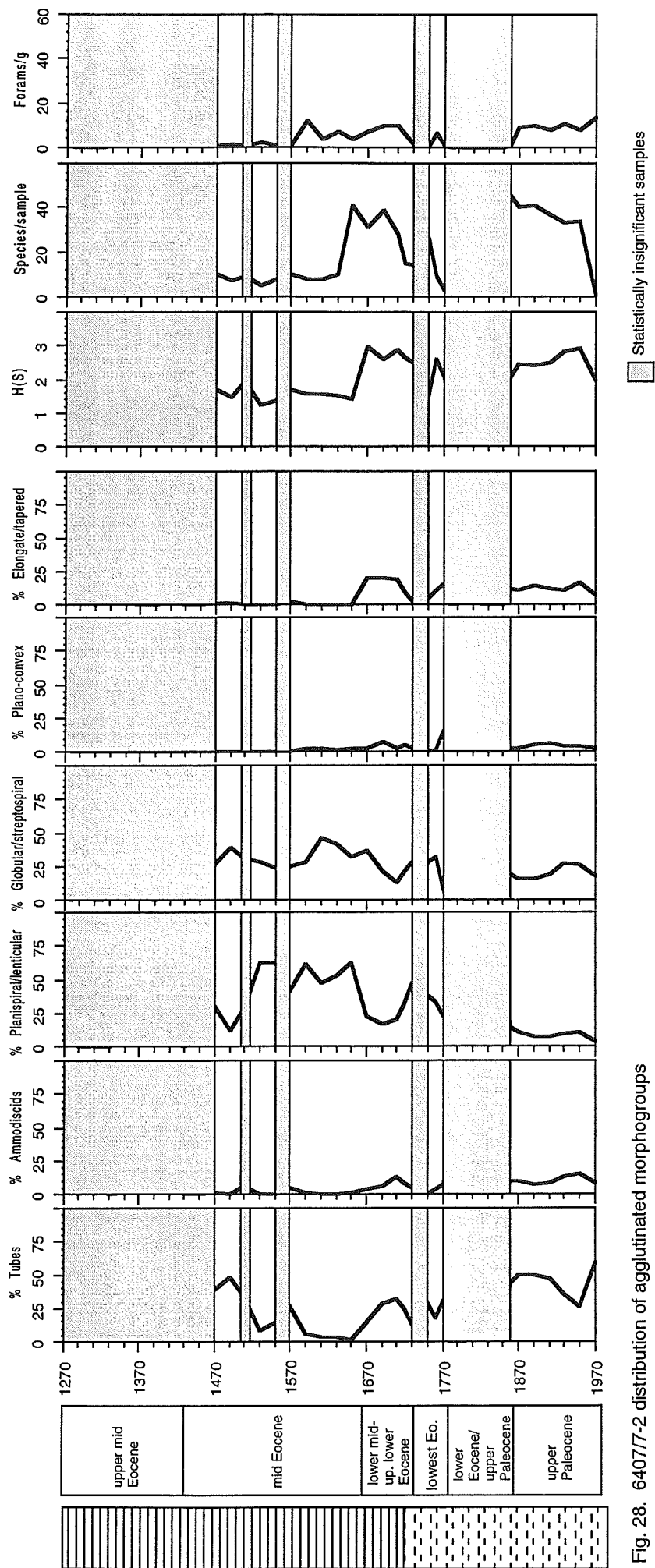
Fig. 28. 6407/7-2 distribution of agglutinated morphogroups
(see Fig. 27 for lithological key)

Statistically insignificant samples

76
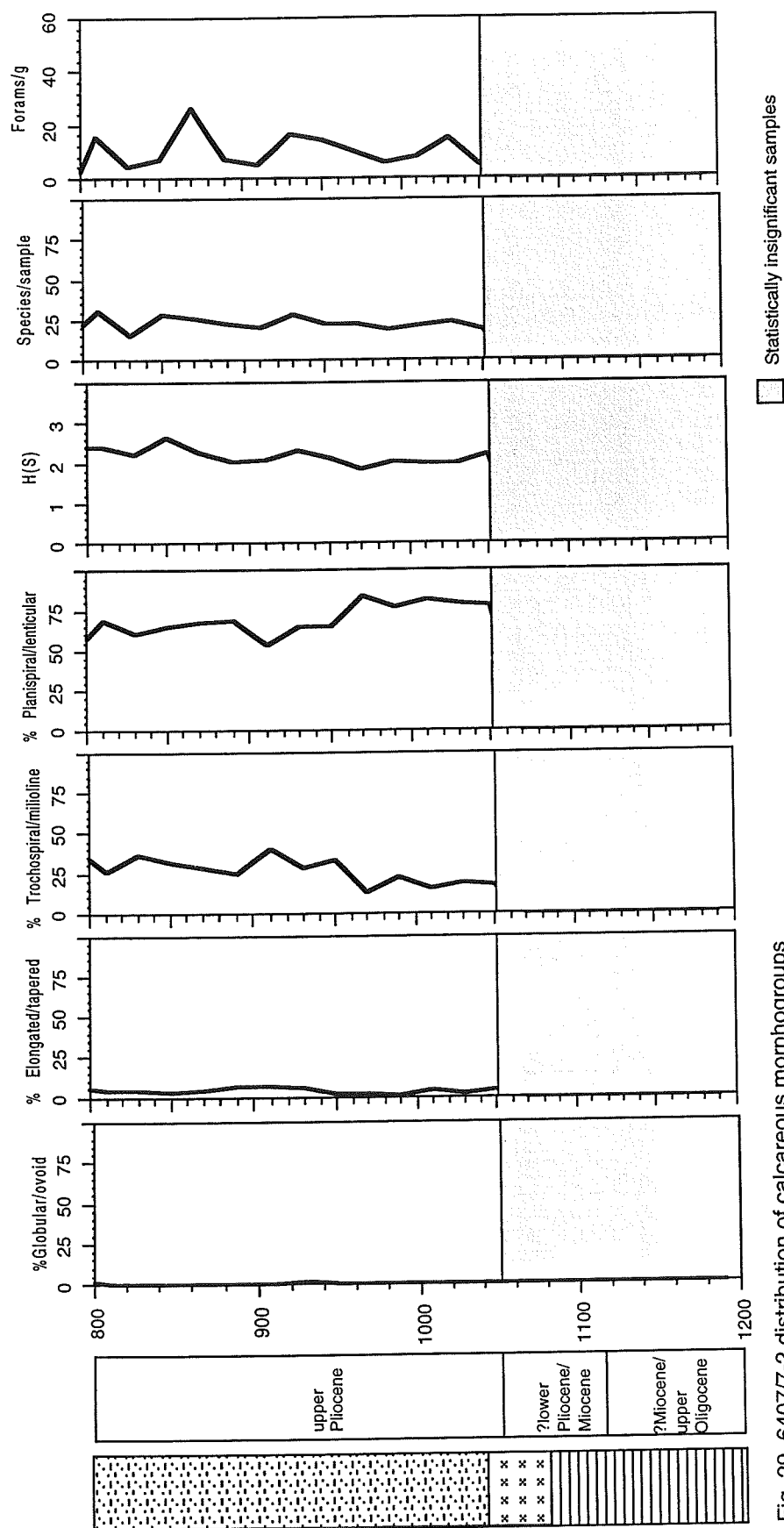
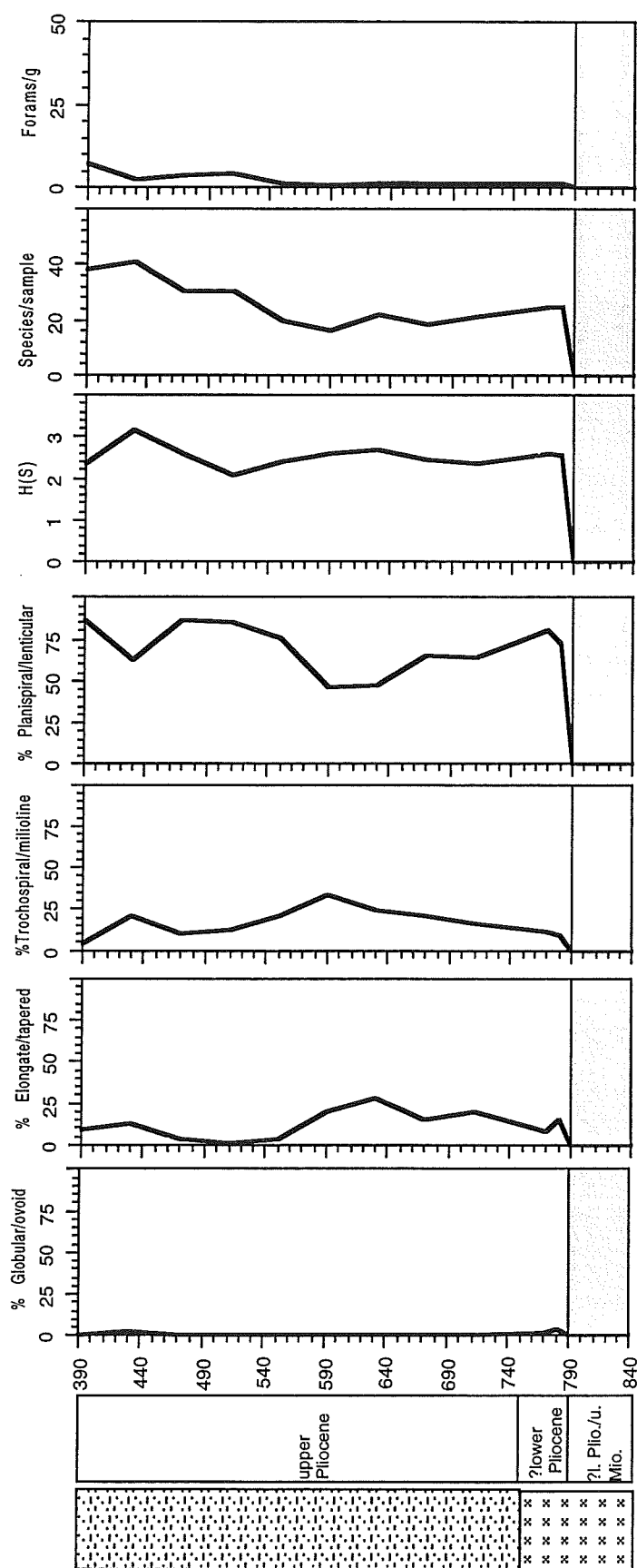Fig. 29. 6407/7-2 distribution of calcareous morphogroups

(see Fig. 27 for lithological key)

77

5.6.3 Calcareous morphogroups

In Well 6407/7-2 calcareous foraminifers appear quite suddenly at 1050m (see Fig. 29). Abundance and diversity are high. In a similar pattern to that seen in well 6407/11-1 the planispiral/lenticular morphogroup and the trochospiral/milioline morphogroup are dominant. H(S) values to the top of the studied section remain at high levels (>2). The small influx of globular forms seen in well 6406/11-1 and 6407/9-3 is also noted here at the top of the section.

5.6.4 Summary

The high H(S) values at the bottom of the section indicate a well partitioned deep environment with at least some current activity indicated by the presence of high numbers of robust tubular *Bathysiphon* and *Rhabdammina* type tubes which are considered to be suspension feeders (Jones and Charnock 1985; Jones 1988). A mid bathyal depth is indicated by the high numbers of *S. spectabilis* and the lack of any true abyssal forms such as rzehakinids. The appearance of *S. spectabilis* and absence of calcareous benthics indicate a relatively deep environment probably just at the lysocline. The impoverished interval is accompanied by an increase in TOC values to around 1.5, which indicate that the bottom sediments were probably dysoxic during this interval. This would explain the decrease in foraminiferal abundance and diversity. Above this interval H(S) values are high (>2.5) indicating a return to favourable conditions possibly below the CCD as no calcareous benthics and no calcareous cemented agglutinates are observed. At the point where the H(S) drops sharply, high abundance and dominance by a few species is observed. High numbers of *R. amplectens* are found, concomitant with a drop in most of the other morphogroups except the globular/streptospiral group. This may indicate that *R. amplectens* is an opportunistic species better able to cope with adverse conditions. An increase in the TOC values matches the increase in *R. amplectens* and indicate that there were probably dysoxic subsurface conditions. The globular/ovoid groups which are presumed infaunal and better adapted to dealing with low oxygen conditions also increase during this time. The general drop in the abundance of agglutinated foraminifers is associated with an increase in the siliceous fossils which suggests that increasingly adverse conditions for benthic life were created.

The high TOC values between 1100m and 1200m correspond with a drop in abundance of all microfossils. Above this interval between 1040m and 1080m there is a glauconite rich interval. The presence of glauconite indicates extremely low sedimentation rates with very little or no current activity. No foraminifers are found within this interval.

As in Well 6406/11-1 calcareous foraminifers appear abruptly in the upper Pliocene indicating that an hiatus exists for at least part of the lower Pliocene. H(S) values of around 2 amongst the calcareous benthics would seem to indicate a well partitioned environment, however there is dominance within the foraminifers by four taxa i.e. *Melonis barleeanum, Cibicides grossus, Cassidulina teretis* and *Cibicides lobatulus* which are considered to be motile species. This may indicate that subsurface conditions were not optimum. As in Well 6406/11-1 and Well 6407/9-3 the

small influx of *Fissurina* spp. and *Oolina* spp. is also noted here. There is also an increase in cold water and shallow water species towards the top of the section.

5.7 Well 6407/9-3

5.7.1 Biogenic components

The percentages of the various biogenic components are shown in Fig. 30. As in the previous wells agglutinated foraminifers dominate in the lower part of the studied section having abundance's of over 90%. There is a decrease in abundance around 1380m, above which agglutinated foraminifera recover and show several peaks in abundance e.g. at 1280m, 1160m, 1060m and 1000m before disappearing at 880m. Above this they appear only sporadically and in low abundance. Calcareous benthics are extremely rare until 780m where they suddenly appear in high numbers, above this level they are dominant. Planktic foraminifers occur in only low numbers throughout the whole section. They have one stratigraphically important peak between 1300m and 1320m.

Radiolaria are the most important of the siliceous microfossils and appear for the first time in large numbers at 1360m. They are abundant up to 900m having main peaks at 1040m, 1080m and 1220m. Diatoms appear mainly in the bottom part of the section and are stratigraphically important between 1380m and 1390m. Sponge spicules are unimportant throughout the studied section and the 'others' group has one peak between 850 and 860m which is composed entirely of pyritized burrows/worm tubes. Shell fragments are abundant from 770m upwards but have not been included in the final counts.

5.7.2 Agglutinated morphogroups

Fig. 31 shows the percentages of the various agglutinated morphogroups. At the base of the section the tubular group is dominant. It then shows a fall in abundance with a concomitant increase in the other morphogroups especially the globular and planoconvex groups. Above 1480m the tubes once again increase in dominance to the detriment of the other groups except for the planispiral group which also increases in abundance. Above a short impoverished interval tubes are again initially dominant, before showing a decline to 1240m. At the beginning of this decline the elongate/tapered group shows the biggest increase while towards the top of the interval the planispiral group increase sharply in abundance. Towards the top of the section at 1020m tubes and ammodiscids (mainly *Glomospira charoides*) dominate the assemblages before agglutinated foraminifers decline to very low numbers or are not present at all.

H(S) values are high (over 2) in the lower part of the section both before and after the impoverished interval. At 1220m H(S) values decline sharply and, although they recover briefly around 1160m, the decline continues until zero values are seen at 880m. Foraminiferal abundance is initially high. There is a decrease around the impoverished interval from 1440m to 1300m. After this they decline

79

Fig. 30. Well 6407/9-3 distribution of biogenic components
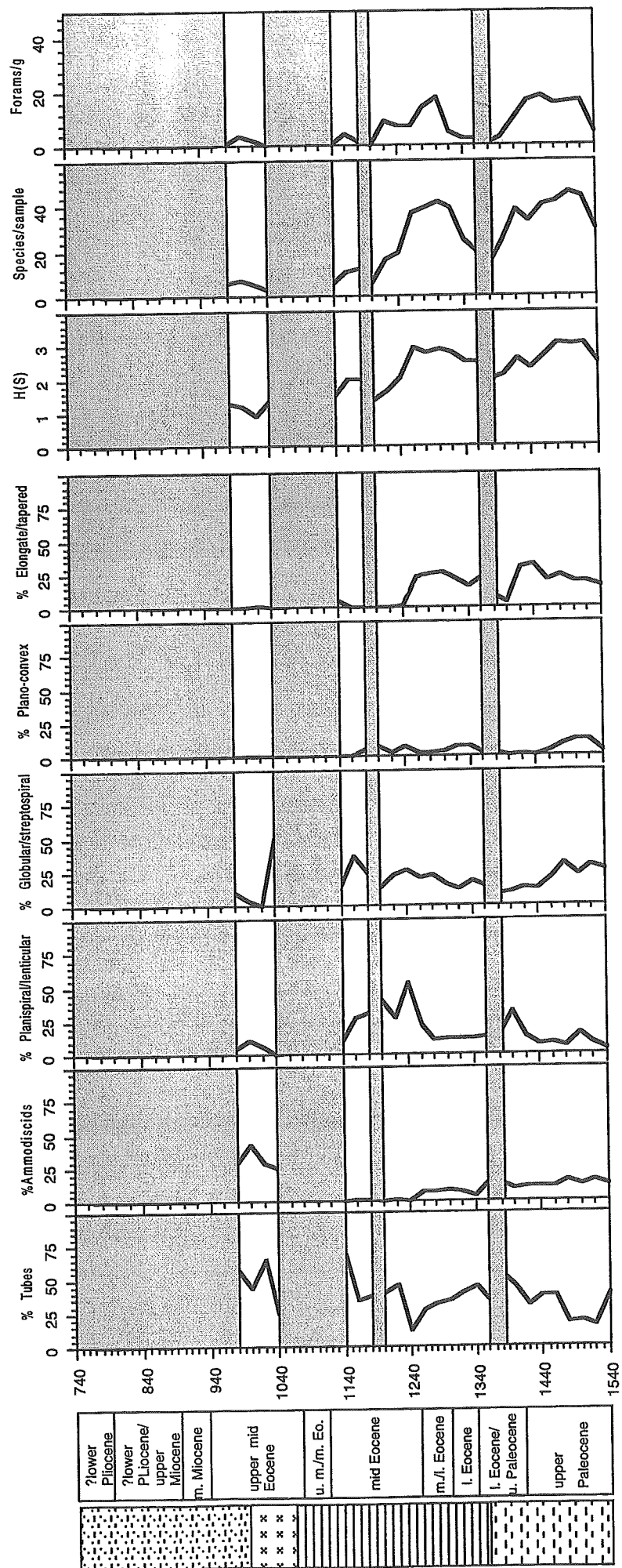
Fig. 31. Well 6407/9-3 distribution of agglutinated morphogroups
(see Fig. 30 for lithological key)

Statistically insignificant samples

81

Fig. 32. Well 6407/9-3 distribution of calcareous morphogroups (see Fig. 30 for lithological key)

82

to very low values by 1140m and remain low to 880m where the disappearance of agglutinated foraminifers is noted.

5.7.3 Calcareous morphogroups

Calcareous benthics appear quite abruptly at 780m (Fig. 32). The dominant morphogroups are the planispiral/lenticular and trochospiral/milioline groups. However, in this well a good proportion of elongated/tapered forms are also seen. The small increase in the globular/ovoid group which occurs in Wells 6406/11-1 and 6407/7-2 is also noted here and again consists mainly of *Fissurina* spp. and *Oolina* spp. H(S) levels are high throughout although abundance i.e. foraminifers/g remains low.

5.7.4 Summary

At the base of the studied section the high H(S) values and the spread between agglutinated morphogroups indicate a favourable environment for both epi- and infaunal life with adequate nutrient supply and some current activity. The tubular forms show a decrease in abundance at the base of the section with a concomitant increase in abundance in all the other morphogroups. H(S) values during this interval are high indicating a well partitioned environment with many ecological niches being filled. The loss of tubular forms may be due to increased current activity as very strong current conditions tend not to be favourable for tubular foraminifers. Their increase towards the impoverished interval may herald a return to quieter conditions allowing them to dominate once more. As in all other wells this interval is typified by large numbers of *S. spectabilis* indicating a position probably just near the lysocline. Well 6407/9-3 shows the least decrease in abundance and diversity out of all the wells studied at the Paleocene/Eocene boundary. This may be due to the fact that it was furthest away from any tectonic and volcanic activity. A return to well ventilated, deep conditions occurs shortly above the impoverished zone where a good spread of morphogroups is seen and both diversity and abundance are high. Again these agglutinated assemblages may have existed below the CCD. The tubular forms and *R. amplectens* show an almost inverse relationship in this well as in Wells 6407/7-2 and 6406/11-1. The dominance by *R. amplectens* is signalled by the drop in H(S) values. above this H(S) values stay low due to the beginning of high biosiliceous sedimentation at around 1240m. Thereafter diversity and abundance decline as siliceous microfossils become more important.

High TOC values are seen at three places through the section: in the impoverished interval, during the period of *R. amplectens* dominance and during the last radiolarians peak. From 770m to 840m, as in well 6407/7-2, there is an interval dominated by glauconite, possibly indicating extremely low sedimentation rates and current activity.

The sudden appearance of abundant and diverse calcareous benthics at 780m indicates that an hiatus probably exists through much of the upper Miocene and lower Pliocene The foraminifers from 780m to 540m show a good spread between morphogroups indicating suitable conditions for both epi- and infaunal life. The short decline in elongate foraminifers between 530m and 470m may indicate slightly reduced nutrient input - the concomitant increase in planispiral forms which are more

opportunistic and can live in a variety of environments supports this. A decrease in the planispiral group and an increase in all other groups around 430m as well as an increase in H(S) values indicate a return to more favourable conditions. The last few samples show a return to dominance by the planispiral group. This is due mainly to a large increase in the numbers of *Elphidium excavatum* f. *clavata*, a shallow/cold water indicator.

5.8 Palaeoecology

5.8.1 Palaeobathymetry

Many studies have attempted to define the bathymetric ranges of benthic foraminifers. One of the first such studies was made by Brady during the Challenger expedition of 1882-1887 when he examined both agglutinated and calcareous foraminifers as reported in Barker (1960) and Jones (1994). Scott *et al.* (1983) presented depth distributions of agglutinated foraminifers from the recent north-west Atlantic and related these findings to Paleogene 'flysch type' assemblages from the Labrador and Newfoundland shelves. These authors found that many of the same genera dominated the Recent Newfoundland slope from 400m to 3200m and the Maastrichtian to Paleogene Newfoundland and Labrador subsurface. Gradstein *et al.* (1994) carried out palaeoslope transects in the Central North Sea and northern Grand Banks to assess lateral changes in assemblage composition with depth and found that diversity increased with depth and that many taxa extended into younger strata in the deeper areas. Jones (1988) also carried out a palaeoslope transect in the Viking Graben for the Upper Paleocene and related his findings to modern analogues. Morkhoven *et al.* (1986) presented data on the upper depth limits of benthic foraminiferal taxa for the Paleogene and Neogene. Several other works have also included estimates of palaeobathymetry and bathymetric ranges of various foraminifers (Tjalsma and Lohmann, 1983; Kaminski *et al.*, 1988; Berggren and Miller, 1989; Schröder, 1986; Charnock and Jones, 1990; Kuhnt *et al.*, 1989, Kuhnt and Collins, 1996; Kuhnt and Kaminski, 1996).

From the studies mentioned above it seems that benthic foraminifers are not strictly depth controlled, other important factors being, for example, sedimentation type and rate, depth of CCD, and especially nutrient and oxygen content of interstitial waters. In shelf and slope areas foraminiferal assemblages tend to be either mixed agglutinated and calcareous or dominated by calcareous benthics. In the deeper and abyssal regions agglutinated foraminifers are more common especially in those areas below the CCD (Pflum and Frerichs 1976; Scott *et al.*, 1983). In general it seems that foraminiferal diversity and abundance is high at mid slope depths and maximum diversity may ocur at depths greater than 3000m although abundance may decrease (Schröder, 1986). This may be due to the fact that most abyssal areas are oligotrophic and such an environment encourages specialisation and competition so that many ecological niches are filled by K- selected species. Shelf and slope areas often tend to be more eutrophic environments. Such environments may be affected by increased current activity, downslope movements, regional factors such as changes in salinity,

temperature and sediment supply are also important. Therefore r-selected species (opportunistic species) which may be more mobile, reproduce quickly, take advantage of abundant food resources and do not require highly specialised niches are better suited to compete in these environments (Schröder, 1986). Agglutinated 'flysch type' assemblages were found from the shelf edge (200m) to abyssal basins (Gradstein and Berggren, 1981), however, they mainly occur below 500m (Scott *et al.*, 1983).

Many of the calcareous benthics found in this study are either still extant or have modern analogues and for these taxa a large body of literature can be found relating to palaeobathymetry. The most relevant to this study are Belanger and Streeter (1980), Mackensen *et al.* (1985), Qvale (1986), Mackensen (1987), Mackensen and Hald (1988), Ostermann and Qvale (1989), Knudsen and Asbjörnsdóttir (1991), Murray (1991), Seidenkrantz (1992), Poole and Vorren (1994).

5.8.2 Organic flux

A pattern of siliceous sedimentation associated with low diversity foraminiferal assemblages was observed by Kuhnt *et al*, (1989) in DSDP Holes 603B, 641A and 543A after the Cenomanian-Turonian Boundary event, in the Lower to Middle Campanian and in the Paleocene and in the Lower Campanian from ODP Leg 159, Hole 959D (Kuhnt *et al.*, in press). This biofacies, 'Biofacies B', was characterised by impoverished assemblages with a whitish colour and typically contained species of *Glomospira, Ammodiscus* and *Rhizammina* spp. (Kuhnt *et al.*, 1989; Kuhnt and Kaminski, 1990). Kuhnt *et al.* (1989) proposed that these biosiliceous, radiolarians-rich sediments indicated high surface productivity. The biofacies was often associated with increased TOC values as in the wells studied here. Kaminski and Kuhnt (1995) postulated that tubular forms with a larger test diameter were to be found in areas of enhanced carbon flux. Although tubes with diameters of >500μm were not observed in this study (Kuhnt and Kaminski's indicator of high organic flux), tubes with larger diameters were observed in the Upper Paleocene when TOC values were slightly higher. The interval with highest TOC values, however, coincides with very sparse and impoverished assemblages containing very few tubes.

Palaeobathymetric interpretations (Fig. 33) and palaeoenvironmental summaries for the wells studied are presented below, based on changes in diversity, relative abundance and changes in morphogroups.

5.9 Summary of palaeoenvironments

By using information from all four wells, eight main palaeoenvironments and associated assemblages can be distinguished:

1. Deep water generally quiescent conditions during the upper Paleocene with some local stronger currents. Deposition was just at the lysocline as witnessed by the appearance of the calcareous
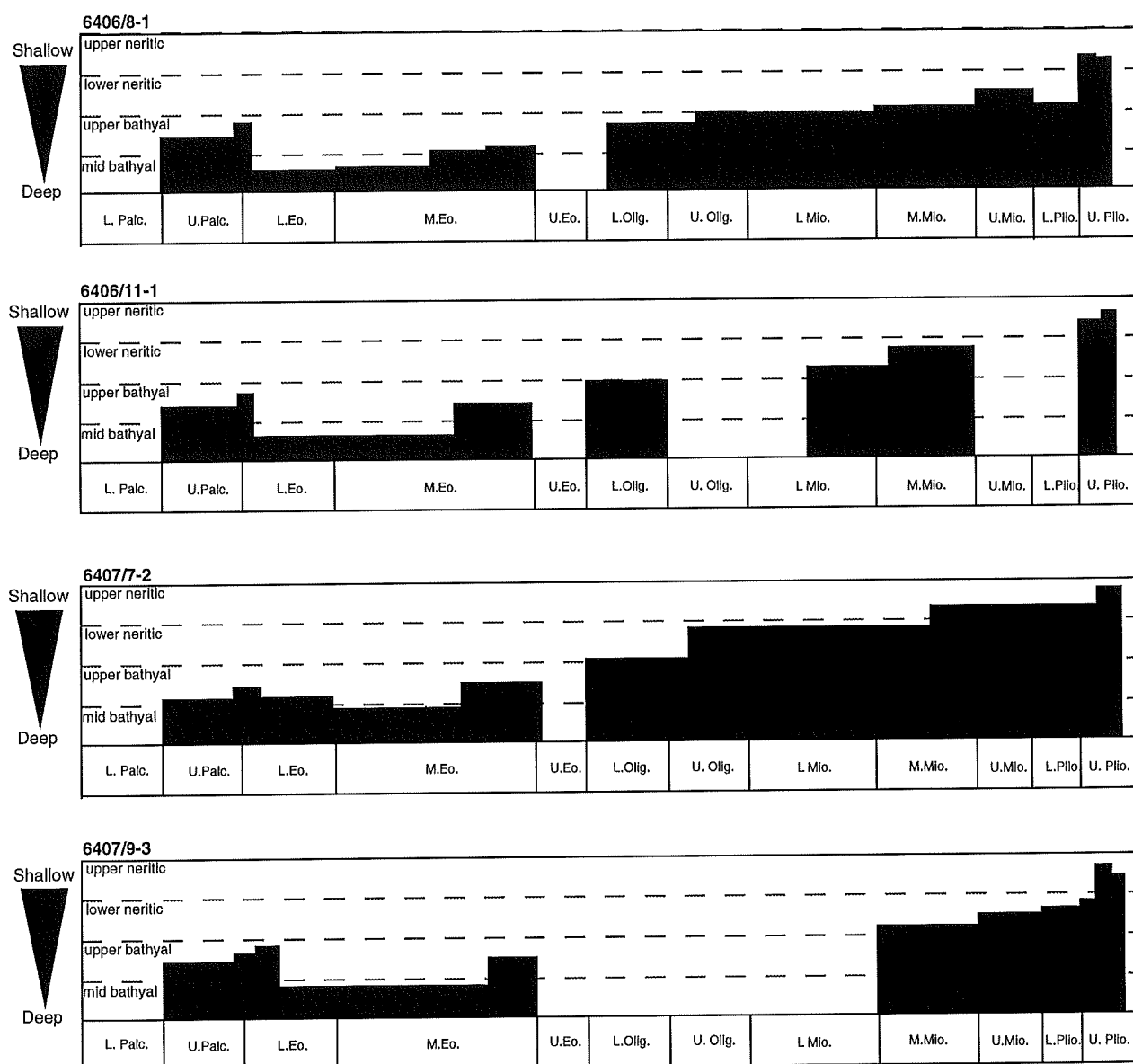
Figure 33. Palaeodepth estimates for the Halten Terrace wells based on changes within the morphogroups.

cemented foraminifer *Spiroplectammina spectabilis* and the absence of calcareous benthics or planktics. Tubular forms e.g. *Rhabdammina* and *Bathysiphon* are dominant. Ammodiscids, haplophragmoidids and *Karrerulina* spp. are also common.

2. Impoverished/barren intervals at or near the Paleocene/Eocene boundary. These probably relate to the opening of the Norwegian-Greenland Sea, which produced uplift in the area with associated tuff ejection. The decrease in tubular suspension feeders and increase in other morphogroups, especially the elongate/tapered and planispiral/lenticular groups point to increased current activity in the area. Tuff production may have increased surface productivity leading to higher TOC values, which in turn may have produced dysoxia at the sea floor, favouring the more opportunistic and infaunal morphogroups. Pyritized diatoms are common at the top of the interval.

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3. Assemblages containing the planktic foraminifer *Subbotina patagonica*. The appearance of subbotinids indicates a position above the CCD and may also imply a cooling of at least the surface waters as subbotinids are thought to be cool water indicators (Pardo *et al.*, 1997). The tubular forms increase in abundance and the rest of the fauna e.g. *Karrerulina conversa, Recurvoides* spp., together with reduced numbers of ammodiscids and lower TOC values indicate relatively deep, quiescent, mid bathyal waters and a return to more oxygenated conditions.

4. A return to deep sub-CCD conditions with agglutinated assemblages dominated by tubular foraminifers. No calcareous foraminifers planktic or benthic are recorded. The microfossil assemblages, TOC values and lithology indicate that although now below the CCD, the environment must have been very similar to that in environment 3.

5. Dominance of the assemblages by *Reticulophragmium amplectens* and the start of biosiliceous sedimentation. This enhanced surface productivity increased nutrient flux to the sea floor leading to more eutrophic conditions. The decrease in diversity of agglutinated foraminifers towards the top of this interval may also point to shallower conditions.

6. Impoverished assemblages, often with *Glomospira charoides*, dominated by siliceous microfossils. Numerous hiatuses and barren periods indicate an increase in current activity. The high numbers of radiolarians recorded may point to relatively deep waters (>150m) as radiolarians are preferentially found in open ocean environments (Hull, 1996). These assemblages may equate to Biofacies B of Kuhnt *et al.* (1989).

7. The appearance of calcareous foraminifers indicates deepening of the CCD and/or shallowing of the sites to upper slope/outer neritic depths. The appearance of *Turrilina alsatica* may indicate low to intermediate bottom water oxygen conditions (Kaiho, 1991). An interval rich in glauconite indicates very low sedimentation and erosional rates (Wolf, 1991).

8. Rich calcareous foraminiferal assemblages indicating well ventilated waters and bottom conditions. Sediment rates were extremely high due to the uplift and erosion of Fennoscandia. This is reflected in the large number of epifaunal and motile species recorded. Increasing numbers of cold and shallow water indicators are observed up section.

6. Palaeoecologic and biostratigraphic synthesis

6.1 Paleocene

The Cretaceous/Tertiary (K/T) boundary is not found at the sites investigated here as at this time there is a regional unconformity reflecting the Upper Cretaceous-Paleocene syn-rift up-lift (Stuevold and Eldholm, 1996). However, the upper Paleocene assemblages, which are dominated by the opportunistic taxa *Spiroplectammina spectabilis* and ammodiscids, may indicate the final recovery from the K/T. Assemblages dominated by *S. spectabilis* (Event 3 of Kuhnt and Kaminski, 1996) were reported as being characteristic of the recovery phase of the marine ecosystem after the K/T boundary Event indicating an increasing supply of calcium carbonate (Kuhnt and Kaminski, 1996). This '*Spiroplectammina* event' in the Lower Paleocene was also recorded in Hole 959B of ODP Leg 159 along the Côte d'Ivoire-Ghana transform margin (Kuhnt *et al.*, in press). As *S. spectabilis* is a calcareous cemented species, and there are very few or no calcareous species, this points to depths being at or just below the lysocline. Any calcareous foraminifers which were present, may have been dissolved and are not preserved here. The high numbers of opportunistic species may indicate an environment with high nutrient input. The assemblages typical in the Paleocene with high numbers of tubular forms such as *Rhabdammina* and *Bathysiphon* and the occasional appearance of *Rzehakina minima* indicate a relatively deep bathyal environment. The assemblages during the upper Paleocene consist of 'flysch type' assemblages i.e. purely agglutinated assemblages with large numbers of tubular forms, ammodiscids, lituolids, and *Karrerulina* spp. The very fine grained sediments deposited at this time and the fine grained nature of the foraminiferal tests point to quiescent relatively low energy environments, although some current activity must have taken place as indicated by the high number of tubular suspension feeders. Assemblages with a greenish grey colour, due to the colour of the local clays have been described from the Labrador margin as being deposited under slightly oxygen deficient bottom water conditions (Gradstein and Berggren, 1981).

6.2 Paleocene/Eocene boundary

The Paleocene/Eocene boundary in general is associated with a large turnover in benthic foraminifers typified by a large drop in diversity with a large number of extinctions, followed by a period of low diversity and first occurrences, (Thomas, 1990a,b). This faunal turnover has been recognised world-wide by Schnitker (1979), Tjalsma and Lohmann (1983) and Boltovsky and Boltovsky (1989) in the Atlantic and Caribbean, by Miller *et al.* (1987) in the Pacific, by Sigal (1974), Vincent *et al.* (1974) and Nomura (1992) in the Indian Ocean, and by Katz and Miller (1991) Kennet and Stott (1991) and Thomas (1990a,b) in the Antarctic. Pak and Miller (1992) examined benthic foraminiferal and isotope records of the Upper Paleocene to Lower Eocene in the North Atlantic and the Pacific, and compared these results with those from the Southern Ocean. Ortiz (1995) studied the differences in benthic foraminiferal extinction patterns in the North Atlantic and western Tethys. Recently Pardo *et al.* (1997) also studied planktic foraminiferal response at the Paleocene/Eocene boundary from DSDP Site 410 in the Bay of Biscay and found that although they saw no significant extinctions there was a increase in the number of warm water and low oxygen

tolerant species and a decrease in colder water species.

Oxygen and Carbon isotope data suggest that the benthic faunal turnover occurred synchronously with negative excursions of these isotopes during the Upper Paleocene (Pak and Miller, 1992; Thomas, 1990a,b; Kennet and Stott, 1990, 1991; Miller *et al.*, 1987) although Katz and Miller (1991) reported that at Site 577 in the Pacific the benthic turnover seemed to post-date a large negative $\partial^{18}O$ inflection, while at Site 702 in the Atlantic sector of the Southern ocean the extinction began before this inflection. At both sites, however, the majority of the extinctions took place during a large $\partial^{13}C$ decrease. Ortiz (1995) also noted that the extinctions coincided with a negative shift of 2-4% in $\partial^{13}C$ values, and that the extinctions occurred over a shorter time span in the western Tethys than in the North Atlantic and postulated that the environmental changes which triggered the extinctions may have had their origin in the Tethyan region. In Numidian Flysch sites from Northern Morocco Kaminski *et al.* (1996) noted that a change from *Aschemocella* and *Trochamminoides* dominated assemblages to *Glomospira* dominated assemblages occurred at the Paleocene/Eocene boundary rather than a major evolutionary turnover. They concluded that there was an Upper Paleocene to Lower Eocene equivalent of 'Mediterranean outflow water' in which bottom water flowed from western Tethys into the Atlantic

Thomas (1990b) noted that there was an increase in the relative number of infaunal species, across the boundary which implies an increase in productivity or a decrease in oxygen content of the deep waters resulting in less oxidation of organic material. Kennett and Stott (1991) proposed that the deep sea was less oxygenated at this time as a result of reduced deep water circulation. Around the Paleocene/Eocene boundary there is a sudden decrease in $\partial^{18}O$ values. In the absence of any polar ice at this time changes in $\partial^{18}O$ values must have resulted from changes in temperature or salinity of the deep water masses. A major warming of bottom waters to around 10°C in the Upper Paleocene and 13°C in the Lower Eocene was estimated by Miller *et al.* (1987).

During the period around the Paleocene/Eocene boundary there was probably a change in the source area of deep water, a Southern Ocean source either being much reduced or eliminated altogether. Instead of forming in the Southern ocean, deep water might have formed by evaporation and formation of dense warm saline water possibly in the Tethyan region (Brass *et al.*, 1982). This, coupled with a rise in deep sea temperatures, may have caused the faunal turnover (Miller *et al.*, 1987; Katz and Miller, 1991). Pak and Miller (1992), Kennett and Stott (1990,1991) and Thomas (1990a,b) regard this as being the most likely cause for the benthic foraminiferal turnover.

At or around the Paleocene/Eocene boundary in the area investigated there is an interval of reduced abundance or diversity. The top of the low diversity period is typified by the appearance of large pyritized diatoms, *Coscinodiscus* spp. However, no great turnover of the benthic foraminifers is recorded, although, there is a reduction in the percentage of ammodiscids and an increase in diversity shortly above the barren/impoverished intervals. Although the sites in the Norwegian-Greenland Sea may well have been affected by these global oceanographic changes, it is possible that the relatively isolated position of the Norwegian-Greenland Sea and a more local event i.e. the opening of the

Norwegian -Greenland Sea and associated volcanic activity may have played a greater role. The opening of the Norwegian-Greenland Sea caused uplift in the area followed by a subsequent subsidence through cooling. It is noteworthy that Well 6406/9-3 which would have been furthest away from the spreading area shows the smallest drop in abundance and diversity during this interval.

6.3 Eocene

During the Lower Eocene foraminiferal assemblages described from ODP Leg 104 in the Norwegian-Greenland Sea were found to be similar to those of other North Atlantic drill sites as described by Berggren and Schnitker (1983), Gradstein and Berggren (1981), Miller, Gradstein, and Berggren (1982), Murray (1984, 1987) and King (1989) amongst others, with bathyal type assemblages (Zones D and E at Site 645) being similar to the 'flysch type' or 'Type A' Assemblages described by Gradstein and Berggren (1981) and Miller et al. (1982). These assemblages would appear to have a world wide distribution (Gradstein and Berggren, 1981; Kaminski et al., 1988; Miller, et al., 1982) and have often been observed in slope basins and rapidly subsiding troughs with restricted bottom water circulation and rapid sedimentation, which conditions favour the preservation of agglutinated foraminifers. The similarities of the fauna from the Vøring Plateau and the North Sea Basin during the Lower Paleogene points to there having been a deep water connection between the two basins at this time. The oldest sediments (Eocene) recovered from Site 643 indicate that bathyal conditions prevailed on the Vøring Plateau at this time with deep water connections to the Labrador Sea, North Atlantic and North Sea, as benthic assemblages from all three areas are comparable (Osterman and Qvale, 1989).

This agrees with the findings of Kaminski et al. (1990) who concluded that a deep water connection between the Norwegian-Greenland Sea and the northern Atlantic must have existed by the uppermost Lower Eocene, as their Glomospira assemblage was found not only in the Labrador and Norwegian Seas but also at several other locations in the Atlantic and in the Mediterranean. Further evidence for continued connections was provided by the sequential FO of S. compressa and Psamminopelta sp. at Site 647 in the Labrador Sea and Site 643 in the Norwegian Sea. Several Lower abyssal taxa however, e.g. Spiroplectammina cubensis were not found at Site 643 which may indicate that the Greenland-Scotland Ridge during the Lower Paleogene acted as a filter to lower bathyal to abyssal taxa with connections possibly being limited to the relatively shallow Faroe-Shetland channel (Kaminski et al., 1990).

At the Halten Terrace sites, however, assemblages containing large numbers of Glomospira spp. and associated taxa e.g. Karrerulina spp., are also found in the Paleocene. Glomospira spp. were also reported to range into the Paleocene by Gradstein and Bäckström (1996). Nagy et al., (in press) also recorded numerous Glomospira spp. from the western Barents Sea during the Upper Paleocene and Eocene and Glomospira charoides was observed in central Spitzbergen in the Lower Cretaceous (Nagy et al., 1990). This may imply that due to its geographical position on the western slope of the Vøring Plateau, ODP Site 643 (Kaminski et al., 1990) was isolated from the Halten Terrace and sites

to the east of the Plateau, and was first connected to the main North Atlantic in the Lower Eocene through the Faroe-Shetland channel, allowing the migration of species from the North Atlantic/Labrador Sea into the area. Another possible explanation for the difference is that in most of the sites on the Halten Terrace *Glomospira* spp. have a bimodal distribution pattern, being recorded in the Paleocene and in the mid Eocene and only rarely observed in between. It is possible that since the earliest sediments recovered at Site 643 were Eocene in age the Paleocene occurrence of *Glomospira* spp. was not observed.

Hulsbos *et al.* (1989) compared faunas from DSDP Site 338 (Norwegian Sea), and coeval faunas from the main North Atlantic basins and bordering epicontinental seas and also concluded that Lower Eocene faunas at all sites closely resembled one another, indicating that a marine connection existed between the Norwegian-Greenland Sea and the North Atlantic. However, these authors stated that planktic foraminifers were rare or absent in comparison to sites in the main North Atlantic, and they concluded that the Greenland-Scotland (Iceland Faroe) Ridge had inhibited the direct exchange of bottom and surface water until its Mid Miocene submergence. They further postulated that any observed similarities between the assemblages were due to migration through the epicontinental seas of NW Europe rather than through open marine connections across the Iceland Faroe Ridge. In contrast, Miller and Tucholke (1983) argued that surface water connections between the North Sea and the North Atlantic had existed since the Lower Eocene and Kaminski *et al.* (1990) stated that planktic foraminiferal assemblages of the Lower Eocene *Subbotina patagonica* Zone (=Zones P7-P8) were practically identical at shallow DSDP sites on the Vøring Plateau, Site 647 in the Labrador Sea and in the central North Sea, indicating good surface water connections.

Planktic foraminifers are recorded in the Lower Eocene on the Halten Terrace. This indicates that most of the sites must have been above the CCD, which during the Lower Eocene was probably very shallow, possibly less than 900m (Hulsbos *et al.*, 1989). Following this short interval there is a return to assemblages wholly composed of agglutinated foraminifers. Throughout the mid Eocene diversities and abundances decrease and there is a mid Eocene interval which is dominated by *Reticulophragmium amplectens.* A decrease in the percentage of tubular forms is also observed in this interval. Many of the foraminifers are also less finely grained and do not have such smoothly finished tests as species in the Paleocene and lower Eocene. It was during this time that siliceous microfossils began to become very abundant, possibly as a result of increased upwelling in the area. This large increase in siliceous sedimentation to the sea floor, although enhancing nutrient supply, would also have the effect of lowering the pH of the waters. This would increase the likelihood of dissolution of calcareous tests. This may be the reason why *S. spectabilis* and calcareous benthics are so rarely seen during the mid-Eocene. Therefore, it is possible that the Eocene assemblages are residual dissolution assemblages rather than primary assemblages.

A large increase in nutrients to the sea floor may also have caused dysoxic subsurface conditions favouring an assemblage of opportunistic, highly adaptable species. This appears to be the case for the *Glomospira* assemblages in the upper mid-Eocene.

6.4 Eocene and Oligocene

Agglutinated dominated assemblages disappeared from the North Sea during the Upper Eocene to Oligocene (Gradstein and Berggren, 1981) and in the Labrador Sea at Site 647 agglutinated foraminifers disappeared within 4my of the Eocene/Oligocene boundary (Kaminski *et al.*, 1989a). At shallow water sites on the Vøring Plateau there is a change from predominantly agglutinated assemblages in the Eocene to corroded calcareous ones in the Oligocene (Hulsbos *et al.*, 1989; Kaminski *et al.*, 1989a). The increase in calcareous sediments may have been caused by a combination of cold Arctic water entering the Norwegian-Greenland Sea as advocated by Berggren and Schnitker (1983) and a drop in sea level with associated lowering of the CCD (to around 1000m) (Hulsbos *et al.*, 1989). Kaminski *et al.* (1989a) however, suggested that, since such a turnover is observed also in the Labrador Sea, Beaufort Sea and Viking Graben, an advection of Atlantic water into the Norwegian Sea was the cause of the changes. This faunal turnover is not seen in the deep Norwegian Sea as the relatively shallow depth of the Greenland-Scotland Ridge may have prevented the exchange of deep waters and led to stratification of the Norwegian Sea waters. This would have favoured the preservation of agglutinated assemblages at deeper sites of the Norwegian Sea, where many species which disappear in shallower areas at the Eocene/Oligocene boundary range into the Miocene (Kaminski *et al.*, 1989b; Kaminski *et al.*, 1990).

Oxygen and Carbon isotope data suggest that a northern source of bottom water developed towards the top of the Eocene which resulted in enhanced bottom currents which increased erosion and controlled sedimentation (Miller and Tucholke, 1983; Miller and Fairbanks 1983). There is also considerable seismic evidence for an increase in bottom water circulation around the Eocene/Oligocene boundary (Hull, 1996 and references therein)

In the Halten Terrace area a turnover in foraminiferal assemblages is observed from poor agglutinated assemblages to barren/impoverished assemblages heavily dominated by siliceous microfossils, although much of the Upper Eocene sediments may be missing (Gradstein and Bäckström, 1996). In Leg 151, Site 913 on the East Greenland margin there was also a period of enhanced siliceous sedimentation during the Upper Eocene and earliest Oligocene (Hull, 1996) which corresponds to the high biosiliceous sedimentation found in this study. Hull (1996) related this increase to increased productivity and upwelling. During the Oligocene there was a fall in sea level (Stuevold and Eldholm, 1996), which combined with the dominantly siliceous sedimentation, and probable increase in current activity, accounts for the very poor agglutinated to calcareous assemblages observed. Occasional appearances of such species as *Melonis barleeanum*, an adaptable, motile species, again point to adverse conditions where only a few opportunistic species could survive.

6.5 Oligocene and Miocene

During the Oligocene the main North Atlantic waters became more oxygenated and less corrosive enabling the preservation of calcareous benthic foraminiferal assemblages (Hulsbos *et al.*, 1989;

Kaminski *et al.*, 1990), while in the Norwegian Sea and on the Norwegian Shelf there is evidence of a change in the lower Mid Miocene from a siliceous rich fauna to a calcareous rich one. Sites 907 and 913 on the Iceland Plateau and East Greenland Margin have also been reported as being highly siliceous both during the Mid and Upper Miocene (Hull *et al.*, 1996). This change in sedimentation may be related to an increase in surface water circulation due to beginning of overflow across the Iceland-Faroe Ridge. Sea level also rose through the Miocene (Stuevold and Eldholm, 1996) and in the Upper Miocene many modern calcareous species began to appear.

The decrease in siliceous sedimentation and an increase in water depth together with more vigorous circulation across the Greenland-Scotland Ridge around the Mid to Upper Miocene, (approximately 13-11Ma) and overflow through the Denmark Strait during the Upper Miocene (approximately 7.5-7Ma), (Eldholm *et al.*, 1989) were probably responsible for the appearance of the first calcareous assemblages and bolboforms in the Halten Terrace wells. This all points to improved conditions for benthic life due to increased ventilation of bottom waters. The increased circulation and the beginning of uplift in the Norwegian shelf area, however, may also be responsible for the many barren areas and hiatuses recorded during this interval. A period of non-sedimentation and low current activity around the upper Miocene to lower Pliocene probably gave rise to the glauconite dominated sediments seen in Wells 6407/7-2 and 6407/9-3.

6.6 Pliocene

The lower Pliocene is not well represented on the Halten Terrace and there may even be a regional hiatus at this time. There is also a large drop in sea level (Stuevold and Eldholm, 1996) due mainly to tectonic uplift. Subsequent fluctuations in sea level are a response to major glacial events (Stuevold and Eldholm, 1996). Concomitant with this drop in sea level is a change in lithology to largely unconsolidated sands and a dramatic increase in sedimentation rates. This large increase in sediment is mainly due to erosion of the uplifting margin together with the later deposition of tills and glaciomarine material.

The upper Pliocene assemblages show a change to well preserved and diverse assemblages. There is often dominance by just a few species e.g. *Melonis barleeanum, Cassidulina teretis* at the base of the upper Pliocene sections. These species may be more adapted to survive in an area with high sedimentation rates as they are presumed to be motile species. They are also indicators of relatively deep warm waters. Decreasing water depths and decreasing water temperatures up section are indicated by the appearance of *Elphidium excavatum* forma *clavata* and *Quinqueloculina seminulum*. This change in assemblage reflects the growing deterioration of climate and the onset of northern hemisphere glaciation.

7. Conclusions

7.1 Biostratigraphy

A palaeoceanographic summary is given in Fig. 32

Four wells from the Norwegian shelf area on the Halten Terrace have been studied and a biostratigraphic scheme for the Cenozoic has been erected using mainly benthic foraminifers together with diatoms, radiolarians and bolboforms, where available. Fourteen assemblages were recognised ranging from wholly agglutinated assemblages to wholly calcareous ones.

The Cenozoic can be split into three basic units based on foraminiferal assemblages:

1. The lower Paleogene (upper Paleocene to mid Eocene) is dominated by agglutinated foraminiferal assemblages.

2. In the Oligocene and lower Miocene there is a domination by siliceous microfossils and a large number of barren areas and/or hiatuses. Foraminiferal assemblages are impoverished with either agglutinated (Oligocene) or calcareous (Miocene) foraminifers.

3. In the Neogene (upper Miocene to Pliocene) there is an increase in the number of calcareous foraminifers and a concomitant drop in the abundance of siliceous fossils. The upper Pliocene is characterised by abundant and diverse assemblages and very high sedimentation rates.

The lower Paleocene and upper Eocene are not documented in the wells studied

The biostratigraphy has been correlated with other schemes from the same or adjacent areas. Biostratigraphical schemes from the Norwegian Sea were found to be most applicable, while those from the North Sea, although similar in many respects, could not be used if based upon planktic foraminifers. Calcareous benthic zonations could also not be used in the Halten Terrace area for the Paleogene and lower Neogene.

The last observed occurrences in each well were correlated against an optimum extinction sequence for the North Sea and Halten Bank area. Although some outliers were observed the two schemes were found to be in agreement.

7.2 Palaeoecology and palaeoceanography

Using evidence from changes in foraminiferal morphogroups and in foraminiferal and other microfossils distribution patterns, the succession of palaeoenvironments on the Halten Terrace during the Cenozoic has been outlined. The foraminiferal patterns are influenced by tectonic movements, sedimentation rates, circulation patterns and changes in organic flux.

During the upper Paleocene the sites studied experienced deep water conditions close to the lysocline with relatively nutrient rich, warm waters with medium strength bottom currents. The

opening of the Norwegian-Greenland Sea lead to increased current activity together with some uplift and a deepening of the CCD. The influx of subbotinids, which live at or lower than the thermocline and are generally indicative of cooler waters, possibly indicate cool surface to intermediate waters during the earliest Eocene (Pardo *et al.*, and references therein, 1997). The Eocene is characterised by a return to deeper sub-CCD conditions with a reduced nutrient input. The mid Eocene heralds the start of siliceous sedimentation, increased organic matter accumulation and a deterioration of subsurface oxygen conditions. The Oligocene and lower Miocene were times of increased current activity, high biosiliceous input and falling sea levels. The mid to upper Miocene signals the start of improved circulation through the Iceland-Faroe Ridge and the Denmark Strait. At the same time siliceous input decreases and subsurface oxygen conditions improve. The upper Pliocene is characterised by a dramatic increase in sedimentation rates together with cooling and further shallowing of the sites.

	Tectonics	Palaeoceanography	Lithology	Siliceous microfossils	Calcareous benthics	Agglutinated foraminifera	Summary

Column (ages, left):
- l. Plio.
- e.Plio
- l. Mio.
- m.Mio.
- e.Mio.
- l. Olig.
- e.Olig.
- l. Eo.
- m.Eo.
- e. Eo.
- l. Palc

Tectonics: Uplift of Norwegian margin. Change of pole of rotation. Greenland joins N. American plate. Opening of Norwegian-Greenland Sea.

Palaeoceanography:
Sea-level fall
Deep water connection Fram Strait
Flow through Denmark Strait
Overflow Iceland-Scotland Ridge
Sea level fall
CCD deepens (>1000m)
Shallow CCD (>1000m)
Upper to mid bathyal exchange. Faeroe-Shetland channel

Lithology:
Sand/sandstones plus occasional rock fragments
Glauconite
Siltstones, Silty claystones Occasional sand and limestone stringers. Traces of pyrite.
Claystones and occasional shales. Traces pyrite, tuff and limestone.

Calcareous benthics: No calcareous benthics seen. Possibly due to dissolution

Summary:
colder and shallower uplift + inc. in sed^{n}.
'Null' sedimentation.
Shallowing of sites plus increased ventilation of waters.
Low to intermediate bottom water oxygen conditions.
Barren areas/hiatuses common. Increased bottom currents.
Eocene/Oligocene turnover not seen in deep Norwegian Sea.
upper Eocene hiatus
Greatly increased silicious sedimentation decreases pH. Increases $CaCO_3$ dissolution. Dysoxic bottom conditions.
Return to sub-CCD conditions. Reduced organic flux to sea floor.
Sites above CCD. Influx of colder water.
uplift. Inc. bottom currents
Quiescent, relatively low bottom current activity. Deposition around lysocline. Nutrient rich, warm waters.

Figure 34. Summary of palaeoenvironments, lithologies and events on the Halten Terrace during the Tertiary. For the Microfossils groups increasing thickness of line equals increasing abundance/diversity.

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8. Taxonomy

The supregeneric classification follows largely the scheme of Loeblich and Tappan (1987). Where appropriate, emendations e.g from Jones (1994), Gradstein and Kaminski (1989) and Kaminski and Geroch (1993) were used. Both agglutinated and calcareous taxa are presented alphabetically. The following abbreviations have been used: cf. for taxa similar to the named species but differing in some detail, ex. gr. for the sake of an example, sp.1, 2 etc. for species which do not match published descriptions, sp. spp. for taxa not identified to specific level.

Some depth and stratigraphic ranges from the literature are also included (RF1) = Jones (1994), (RF2) = Jones and Charnock (1990) and (RF3) = King (1989).

Agglutinated foraminifers

Adercotryma agterbergi **GRADSTEIN & KAMINSKI 1989**
Plate 6, Fig. 1
1990 *Adercotryma agterbergi* Kaminski *et al*, p. 367, pl. 4, fig. 5a-b.
1994 *Adercotryma agterbergi* Gradstein *et al.*, pl. 7, figs. 12-14. pl. 8, figs. 1-5.

Adercotryma glomeratum **(BRADY 1878)**
1986 *Adercotryma glomerata* Schröder, p. 47, pl. 16, figs. 10, 11.
1990 *Adercotryma glomeratum* Charnock & Jones, p. 185, pl. 10, figs. 1-3; pl. 22, fig. 1.
1994 *Adercotryma glomeratum* Jones, p. 41, pl. 34, figs. 15-18.
Stratigraphic Range: Middle Eocene - Recent (RF1)
                         Middle Eocene - Early Oligocene (RF2)
Depth Range: 14 - 2740 fm (RF1)

Ammobaculites deflexus **(GRZYBOWSKI 1901)**
1993 *Ammobaculites deflexus* Kaminski & Geroch, p. 274-275, pl. 14, figs. 3a-4e.

Ammodiscus cretaceus **(REUSS 1845)**
Plate 5, Fig. 1
1984 *Ammodiscus cretaceus* Labude, p. 69, pl. 1, fig. 7.
1988 *Ammodiscus cretaceus* Kaminski *et al.*, p. 213, pl. 3, fig. 7.
1990 *Ammodiscus cretaceus* Kuhnt , p. 313, pl. 1, figs. 2-3.
1990 *Ammodiscus cretaceus* Charnock & Jones, p. 154, pl. 2, figs. 1-3; pl. 14, fig. 3.
1992 *Ammodiscus cretaceus* Morlotti and Kuhnt, p. 221, pl. 1, figs. 1-2.
Stratigraphic Range: Santonian - Early Oligocene (RF3)
                         Albian - Oligocene (RF2)

Ammodiscus pennyi **CUSHMAN & JARVIS 1928**
Plate 5, Fig. 3
1988 *Ammodiscus pennyi* Kaminski *et al.*, pp. 184-185, pl. 3, figs. 9-10.
1990 *Ammodiscus pennyi* Kuhnt, p. 313, pl. 1, fig. 6.

Ammodiscus peruvianus **BERRY 1928**
1988 *Ammodiscus peruvianus* Kaminski *et al.*, p. 185, pl.3, figs. 11-12.
1992 *Ammodiscus peruvianus* Morlotti and Kuhnt, p. 221, pl. 1, fig. 4.

Ammodiscus tenuissimus GRZYBOWSKI 1897

Plate 1, Fig. 2

1993 *Ammodiscus tenuissimus* Kaminski & Geroch, p. 253, pl. 5, figs. 1-3b.

1996 *Ammodiscus tenuissimus* Kaminski et al., pl. 1, fig. 4.

Ammolagena clavata (JONES & PARKER 1860)

1988 *Ammolagena clavata* Kaminski et al, p. 185, pl. 3, fig. 24.

1990 *Ammolagena clavata* Kaminski et al, p. 365, pl. 3, fig. 1.

1990 *Ammolagena clavata* Charnock & Jones, p. 155, pl. 2, fig. 9; pl. 14, fig. 7.

1994 *Ammolagena clavata* Jones, p. 46, pl. 41, figs. 12-16.

Stratigraphic Range:	Late Paleocene - Recent (RF1)
	Late Paleocene - Early/Middle Miocene (RF2)
	Late Paleocene - Early Oligocene (RF3)
Depth Range:	100 - 2000 fm (RF1)
	60 - 4440 m (RF2)

Ammomarginulina aubertae GRADSTEIN & KAMINSKI 1989

Plate 5, Fig. 12

1989 *Ammomarginulina aubertae* Gradstein & Kaminski, p. 74, pl. 3, figs. 1-8, pl. 4, figs. 1-3, text-fig. 2.

1990 *Ammomarginulina aubertae* Charnock & Jones, p. 179, pl. 9, figs. 6-8; pl. 20, fig. 7..

1994 *Ammomarginulina aubertae* Gradstein et al., pl. 6. figs. 15-22

Stratigraphic Range:	Eocene (RF2)
Depth Range:	2500 - 5779 m (RF2)

Ammosphaeroidina pseudopauciloculata (MJATLUK 1966)

1988 *Ammosphaeroidina pseudopauciloculata* Kaminski et al., p. 193, pl. 8, figs 3-5.

1990 *Ammosphaeroidina pseudopauciloculata* Kuhnt, p. 321, pl. 5, fig. 1.

1994 *Ammosphaeroidina pseudopauciloculata* Gradstein et al., pl. 3. figs. 1-7.

Bathysiphon annulatus (ANDREAE 1890)

1988 *Bathysiphon annulatus* Kaminski et al., p. 184, pl. 1, figs. 16-17.

1990 *Bathysiphon annulatus* Charnock & Jones, p. 149, pl. 1, fig. 30; pl. 13, fig. 10.

Bigenerina sp.1

1990 *Bigenerina* sp.1 Charnock & Jones, p. 184, pl. 9, figs. 19-20; pl. 21, fig. 8.

Stratigraphic Range: Late Paleocene - Middle Eocene (RF2)

Budashevaella multicamerata VOLOSHINOVA 1961

1990 *Budashevaella multicamerata* Kaminski et al, p. 367, pl. 4, figs. 6a-b.

Buzasina galeata (BRADY 1881)

1990 *Buzasina galeata* Charnock & Jones, p. 166, pl. 5, fig. 1; pl. 16, fig. 1.

1994 *Buzasina galeata* Jones, p. 45, pl. 40, figs. 19-23.

Stratigraphic Range:	Maastrichtian - Recent (RF1)
	Campanian - Paleocene (RF2)
Depth Range:	1825 - 2750 fm (RF1)
	713 - 5779 m (RF2)

Clavulinoides aspera (CUSHMAN 1926)

1988 *Clavulinoides aspera* Kaminski et al., p. 194, pl. 8, figs. 11a-12.

Conglophragmium coronatum (BRADY 1879)

1990 *Conglophragmium coronatum* Charnock & Jones, p. 167, pl. 5, figs. 2-3; pl. 16, fig. 2.

1994 *Conglophragmium coronatum* Jones, p. 45, pl. 40, figs. 8-12.

Stratigraphic Range: Santonian - Recent (RF1)

                           Santonian - Early Eocene (RF2)

Depth range: 390-3950 fm. (RF1)

Cribrostomoides sp. 1

Plate 5, Figs. 10, 11

Small, almost spherical *Cribrostomoides*, very finely grained and finished. 4-5 chambers in last whorl. Sutures flush or only slightly depressed.

Cribrostomoides subglobosus forma *subglobosus* (CUSHMAN 1910), emend. JONES *et al.*, (1993)

1993 *Cribrostomoides subglobosus* forma *subglobosus* Jones *et al*, p. 181-193, pl. 3, figs 1-7.

1995 *Cribrostomoides subglobosus* forma *subglobosus* Bender, p. 42, pl. 5, fig. 2.

Stratigraphic Range: Santonian - Recent (RF1)

                           Santonian - Paleocene (RF3)

Depth Range: 500 - 5775 m (RF3)

Cyclammina cancellata BRADY 1879

1994 *Cyclammina cancellata* Gradstein *et al.*, pl 6, fig. 12a,b

1995 *Cyclammina cancellata* Bender, p. 43, pl. 5, fig. 6

Stratigraphic Range: Miocene - Recent (RF1)

Depth Range: 250 - 1000 fm (RF1)

Cyclammina placenta (REUSS 1851)

Plate 4, Fig. 3

1990 *Cyclammina (Cyclammina) placenta* Charnock & Jones, p. 175, pl. 7, figs. 5-12, pl. 18, fig. 4.

1990 *"Cyclammina" placenta* Kaminski *et al*, p. 369, pl. 6, figs. 2a-b.

1994 *Cyclammina placenta* Gradstein *et al.*, pl 6, fig. 7-11.

Stratigraphic Range: Early/Middle Eocene - Middle Miocene (RF2)

Cyclammina rotundidorsata (VON HANTKEN 1876)

1990 *Cyclammina (Reticulophragmium) rotundidorsata* Charnock & Jones, p. 176, pl. 7, figs. 13-15; pl. 19, fig. 1.

1994 *Cyclammina rotundidorsata* Jones, p. 43, pl. 37, figs. 17-19.

1994 *Cyclammina rotundidorsata* Gradstein *et al.*, pl 6, fig. 13-14.

Stratigraphic Range: Eocene? - Recent (RF1)

                           Eocene?, Oligocene - Middle Miocene (RF2)

Depth Range: 1100 - 1900 fm (RF1)

Cystammina pauciloculata (BRADY 1879)

Plate 5, Figs. 5, 8, 10

1986 *Cystammina pauciloculata* Schröder, p. 54, pl. 18, figs. 14, 15.

1990 *Cystammina pauciloculata* Charnock & Jones, p. 168-169, pl. 5, fig. 7.

1994 *Cystammina pauciloculata* Jones, p. 45, pl. 41, fig. 1.

1994 *Cystammina pauciloculata* Gradstein *et al.*, pl 3, fig. 8-12.

May also contain species of *Cystammina sveni* Gradstein & Kaminski (in press) (Gradstein. pers. comm. 1997).

Stratigraphic Range: Campanian - Recent (RF1)

                           Albian?, Campanian - Oligocene (RF2)

Depth Range: 173 - 3950 fm (RF1)

                           181 - 4820 m (RF2)

Dorothia retusa (CUSHMAN 1926)

1988 *Dorothia retusa* Kaminski *et al*, p. 195, pl. 9, figs. 6, 11.

1989 *Dorothia retusa* King *et al*, p. 408, pl. 8.1, figs. 3,4.

1990 *Dorothia retusa* Charnock & Jones, p. 190, pl. 12, fig. 1; pl. 24, fig. 1.

Stratigraphic Range: Campanian - Paleocene (RF2)

Dorothia siegliei GRADSTEIN & KAMINSKI 1989

1990 *Dorothia siegliei* Kaminski *et al*, p. 370, pl. 8, figs. 3-4.

1994 *Dorothia siegliei* Gradstein *et al.*, pl 10, figs. 6-13, pl. 11, figs. 1-2.

Eggerella bradyi (CUSHMAN 1910)

1986 *Eggerella bradyi* Schröder, p. 55, pl. 22, figs. 1-6.

1995 *Eggerella bradyi* Bender, p. 44, pl. 6, fig. 10.

Stratigraphic Range: Oligocene - Recent (RF1)

Depth Range: 129 - 3125 fm (RF1)

Glomospira biedai (SAMUEL 1977)

1990 *Glomospira biedai* Charnock & Jones, p. 156, pl. 2, fig. 10; pl. 14, fig. 8.

Stratigraphic Range: Oligocene (RF2)

Glomospira charoides (JONES & PARKER 1860)

Plate 5, Figs. 4, 9

1988 *Glomospira charoides* Kaminski *et al.*, p.185, pl. 3, figs. 14-15.

1989 *Glomospira charoides* King, p. 455, pl. 9.1, fig.17.

1990 *Glomospira charoides* Kuhnt, p. 313, pl. 1, fig. 11.

1992 *Glomospira charoides* Morlotti and Kuhnt, p. 222, pl. 1, figs. 7-8.

Stratigraphic Range: Early Cretaceous - Late Miocene (RF3)

Glomospira diffundens (CUSHMAN & RENZ 1946)

1988 *Glomospira diffundens* Kaminski *et al.*, p. 185, pl. 3, figs. 18-19.

Glomospira glomerata (GRZYBOWSKI 1898)

Plate 5, Fig. 6

1988 *Glomospira glomerata* Kaminski *et al.*, p. 185, pl. 3, fig. 16.

1990 *Glomospira glomerata* Charnock & Jones, p. 156, pl. 2, fig. 11.

1993 *Glomospira glomerata* Kaminski & Geroch, p. 257, pl. 6, figs. 9-12.

1996 *Glomospira glomerata* Kaminski *et al.*, pl. 1, fig. 13.

Stratigraphic Range: Paleocene - Eocene (RF2)

Glomospira gordialis (JONES & PARKER 1860)

1988 *Glomospira gordialis* Kaminski *et al.*, p. 213, pl. 3, fig. 17.

1990 *Glomospira gordialis* Kuhnt, p. 313, pl. 1, figs. 9-10.

1990 *Glomospira gordialis* Charnock & Jones, p. 156, pl. 2, fig. 12; pl. 14, fig. 9.

1992 *Glomospira gordialis* Morlotti and Kuhnt, p. 222, pl. 1, fig. 9.

Stratigraphic Range: Valanginian - Recent (RF1)

                      Valanginian - Oligocene (RF2)

Depth Range: 50 - 2000 fm (RF1)

                      2225 - 5775 m (RF2)

Glomospira irregularis (GRZYBOWSKI 1898)

1988 *Glomospira irregularis* Kaminski *et al.*, p. 185, pl. 3, figs. 20-21.

1990 *Glomospira irregularis* Kuhnt, p. 313, pl. 1, fig. 12.

1990 *Glomospira irregularis* Charnock & Jones, p. 157, pl. 2, fig. 14; pl. 14, fig. 11.

1992 *Glomospira irregularis* Morlotti and Kuhnt, p. 222, pl. 1, fig. 12.

Stratigraphic Range: Campanian - Eocene (RF2)

***Glomospira serpens* (GRZYBOWSKI 1898)**

1988 *Glomospira serpens* Kaminski *et al.*, p. 185, pl. 3, figs. 22-23.

1990 *Glomospira serpens* Kuhnt, p. 313, pl 1, fig. 4.

1996 *Glomospira serpens* Kaminski *et al.*, pl. 1, fig. 15.

***Haplophragmoides* cf. *concavus* (CHAPMAN 1892)**

1990 *Haplophragmoides* cf. *concavus* Kuhnt, p. 312. pl. 4, fig. 13.

***Haplophragmoides horridus* (GRZYBOWSKI 1901)**

1988 *Haplophragmoides horridus* Kaminski *et al*, p. 189, pl. 5, fig. 11a-b.

1990 *Haplophragmoides horridus* Charnock & Jones, p. 170, pl. 5, figs. 15-16; pl. 16, fig. 9.

Stratigraphic Range: Late Paleocene (RF2)

***Haplophragmoides kirki* WICKENDEN 1932**

Plate 4, Fig. 9

1989 *Haplophragmoides kirki* King, p. 455, pl. 9.1, fig. 19.

1990 *Haplophragmoides kirki* Charnock & Jones, p. 170, pl. 5, figs. 17-18; pl. 16, fig. 10.

1994 *Haplophragmoides kirki* Gradstein *et al.*, pl. 6, figs. 1-6.

Stratigraphic Range: Campanian - Middle Miocene (RF2)

                         Late Cretaceous - Late Miocene (RF3)

***Haplophragmoides* cf. *kirki* WICKENDEN 1932**

Plate 4, Fig. 6

1990 *Haplophragmoides* cf. *kirki* Kaminski *et al*, p. 368, pl. 5, figs. 3a-b.

Coarser grained and somewhat larger than *H. kirki*

***Haplophragmoides porrectus* MASLAKOVA 1955**

Plate 4, Fig. 8

1988 *Haplophragmoides porrectus* Kaminski *et al.*, p. 189, pl. 5, figs. 7-8.

1990 *Haplophragmoides porrectus* Charnock & Jones, p. 171, pl. 5, fig. 19.

Stratigraphic Range: Eocene - Early/Middle Miocene (RF2)

Haplophragmoides* cf. *porrectus

Larger and 'flatter' chambers than *H. porrectus*

***Haplophragmoides stomatus* (GRZYBOWSKI 1898)**

Plate 4, Fig. 7

1993 *Haplophragmoides stomatus* Kaminski & Geroch, p. 264, pl. 11, figs. 1a-2b.

***Haplophragmoides suborbicularis* (GRZYBOWSKI 1896)**

1990 *Haplophragmoides suborbicularis* Charnock & Jones, p. 171, pl. 6, figs. 1-2; pl. 17, fig. 1.

Stratigraphic Range: Late Paleocene (RF2)

***Haplophragmoides walteri* (GRZYBOWSKI 1898)**

Plate 4, Fig. 5

1988 *Haplophragmoides walteri* Kaminski *et al.*, p. 190, pl. 5, figs. 14-15.

1990 *Haplophragmoides walteri* Charnock & Jones, p. 171, pl. 6, figs. 3-4.

1990 *Haplophragmoides walteri* Kuhnt, p. 314, pl. 4, figs. 10-12.

1994 *Haplophragmoides walteri* Gradstein *et al.*, pl 7 figs. 1-5.

Stratigraphic Range: Santonian - Early Miocene (RF3)

                                Santonian - Early/Middle Miocene (RF2)

Haplophragmoides walteri excavatus CUSHMAN & WATERS 1927

1990 *Haplophragmoides walteri excavatus* Kaminski *et al*, p. 368, pl. 5, figs. 6a-b.

1994 *Haplophragmoides walteri excavatus* Gradstein *et al.*, pl 7 figs. 6-9.

Haplophragmoides sp. 1

Plate 4, Fig. 10

Planispiral, evolute coiling with 7 chambers in last whorl. Wall is finely grained. Chambers are almost triangular and sutures are depressed.

Haplophragmoides sp. 2

Planispiral, involute with inflated chambers. Sutures are flush and the wall is smooth and finely grained

Hormosina excelsa (DYLAZANKA 1923)

1990 *Hormosina excelsa* Kuhnt & Kaminski, p. 472, pl. 1, figs. f-i.

1993 *Hormosina excelsa* Kaminski & Geroch, p. 281, pl. 17, figs. 1-4b.

Hormosina ovulum ovulum (GRZYBOWSKI 1896)

1988 *Hormosina ovulum ovulum* Kaminski *et al*, p. 186, pl. 2, fig. 10.

1990 *Hormosina ovulum ovulum* Kuhnt & Kaminski, p. 474, pl. 1, figs. c-e.

1994 *Hormosina ovulum* Gradstein *et al.*, pl. 1, figs. 10-11, pl. 11 fig. 7.

Hormosina velascoensis (CUSHMAN 1926)

1988 *Nodellum velascoense* Kaminski *et al*, p. 187, pl. 1, figs 21-22.

1990 *Hormosina velascoensis* Kuhnt & Kaminski, p. 475, pl. 1, figs. k-l.

Hyperammina dilatata GRZYBOWSKI 1896

1988 *Hyperammina dilatata* Kaminski *et al.*, p. 184. pl. 2, figs. 1-2.

1990 *Hyperammina dilatata* Kuhnt, p. 318, pl. 2. figs. 10-11.

Hyperammina elongata BRADY 1878

1988 *Hyperammina elongata* Kaminski *et al*, p. 184, pl. 1, figs. 14-15.

1990 *Hyperammina elongata* Charnock & Jones, p. 150, pl. 1, fig. 13; pl. 13, fig. 14.

1994 *Hyperammina elongata* Jones, p. 33, pl. 23, fig. 8.

Depth Range: 27 - 4925 m (RF2)

Kalamopsis grzybowskii (DYLAZANKA 1923)

1988 *Kalamopsis grzybowskii* Kaminski *et al*, p. 187, pl. 1, figs. 18-20.

1990 *Kalamopsis grzybowskii* Charnock & Jones, p. 151, pl. 1, figs. 21-22; pl. 13, fig. 21.

1993 *Kalemopsis grzybowskii* Kaminski & Geroch, p. 281, pl. 17, figs. 5a-8.

Stratigraphic Range: Turonian?, Santonian - Eocene (RF2)

Karreriella chapapotensis (COLE 1928)

1990 *Karreriella chapapotensis* Kaminski *et al*, p. 370, pl. 8, fig. 8.

Karreriella horrida MJATLUK 1970

Plate 3, Fig. 8

1988 *Karreriella horrida* Kaminski *et al*, p. 196, pl. 9, figs. 19-20.

1990 *Karreriella horrida* Kaminski *et al*, p. 370, pl. 8, figs. 7-8.

1993 *Karrerulina horrida* Kaminski & Geroch p. 269, pl. 13, figs. 14a-15b.

Karrerulina coniformis (GRZYBOWSKI 1898)

1988 *Karreriella coniformis* Kaminski *et al*, p. 195, pl. 9, figs. 15-16.

1990 *Karrerulina coniformis* Charnock & Jones, p. 195, pl. 25, fig. 9.

1993 *Karrerulina coniformis* Kaminski & Geroch, p. 269-270, pl. 13, figs. 1-4.

Stratigraphic Range: Late Paleocene - Middle Eocene (RF2)

Karrerulina conversa (GRZYBOWSKI 1901)

Plate 3, Figs. 6, 7

1988 *Karreriella conversa* Kaminski *et al.*, p. 196, pl. 9, figs. 17-18b.

1989 *Karrerulina conversa* King, p. 456, pl. 9.2, figs. 23-24.

1990 *Karreriella conversa* Kaminski, p. 370, pl. 8, fig. 5.

1990 *Karrerulina conversa* Charnock & Jones, p. 195-196, pl. 12, fig. 19.

1992 *Karrerulina conversa* Morlotti and Kuhnt, p. 222, pl. 4, fig. 15.

Stratigraphic Range: Santonian?, Campanian - Recent (RF1)

                            Santonian - Early Oligocene (RF3)

                            Santonian?, Campanian - Early Oligocene (RF2)

Depth Range: 1000 - 3950 fm (RF1)

                            49 - 4566 m (RF2)

Lituotuba lituiformis (BRADY 1879)

1988 *Lituotuba lituiformis* Kaminski *et al.*, p. 190, pl. 4, figs. 14-15.

1990 *Lituotuba lituiformis* Charnock & Jones, p. 160, pl. 3, fig. 11; pl. 15, fig.1.

1994 *Lituotuba lituiformis* Jones, p. 44-45, pl. 40, figs. 4-7.

Stratigraphic Range: Late Paleocene - Recent (RF1)

                            Late Paleocene - Oligocene (RF2)

Depth Range: (Carrib. S.Atlantic) 390 - 900 fm (RF1)

                            714 - 4000 m (RF2)

Martinottiella communis (D'ORBIGNY 1846)

Plate 3, Fig. 9

1986 *Martinottiella communis* Schröder, p. 56, pl. 22, fig. 11.

1989 *Martinottiella communis* King, p. 456, pl. 9.2, figs. 4, 5.

1995 *Martinottiella communis* Bender, p. 46, pl. 6, fig. 16.

Stratigraphic Range: Oligocene - Recent (RF1)

                            Late Oligocene - Late Pliocene, Pleistocene? (RF3)

                            Oligocene - Pliocene (RF2)

Depth Range: 714 - 2938 m (RF2)

Paratrochamminoides deformis (GRZYBOWSKI)

1993 *Paratrochamminoides deformis* Kaminski & Geroch, p. 262, pl. 9, figs. 7a-c.

Paratrochamminoides heteromorphus (GRZYBOWSKI 1898)

1988 *Paratrochamminoides heteromorphus* Kaminski *et al.*, p. 191, pl. 4, fig.18.

1990 *Paratrochamminoides heteromorphus* Kuhnt, p. 320, pl. 5, fig. 18.

1996 *Paratrochamminoides heteromorphus* Kaminski *et al.*, pl. 4, figs. 3-5.

Paratrochamminoides irregularis (WHITE 1928)

1988 *Paratrochamminoides irregularis* Kaminski *et al.*, p. 191, pl. 4, fig. 18.

1990 *Paratrochamminoides irregularis* Kuhnt, p. 321, pl. 5, fig. 10.

Plectinella munda (KRASHENINNIKOV 1973)

1988 *Pseudobolivina* sp. Jones p. 148, pl.2, fig. 3

1990 *Plectinella munda* Charnock & Jones, p. 185, pl. 9, fig. 22; pl. 21, fig. 11.

Stratigraphic Range: Campanian - Paleocene (RF2)

Quinqueloculina agglutinata CUSHMAN 1917

1953 *Quinqueloculina agglutinata* Loeblich & Tappan, p. 39, pl. 5, figs. 1-4.

1958 *Quinqueloculina agglutinata* van Voorthuysen, p. 7, pl. 1, fig. 10.

1971 *Quinqueloculina agglutinata* Knudsen, p. 193, pl. 1, fig. 15.

Recurvoides ex. gr. *gerochi* PFLAUMANN 1964

Plate 6, Fig. 6

1988 *Recurvoides* sp. var. *gerochi* Jones, p. 184, pl. 2, fig. 4.

Recurvoides ex gr. *turbinatus* (BRADY 1881)

Plate 4, Fig. 12

1988 *Recurvoides* cf.*turbinatus* Kaminski *et al.*, p. 191, pl. 6, figs 8-9.

1990 *Recurvoides* ex gr. *turbinatus* Charnock & Jones, p. 173, pl. 6, figs. 13-15, pl. 17, fig. 8.

Stratigraphic Range: Santonian - Early/Middle Miocene (RF2)

Depth Range: 400 - 503 m (RF2)

Recurvoides sp. 1

5-6 bulbous chambers in last whorl. Depressed sutures. Wall is fine to medium grained.

Recurvoides sp. 2

Plate 6, Fig. 2

4 elongated chambers in last whorl. Sutures generally flush. Small, the wall is smooth and finely grained.

Recurvoides sp. 3

Plate 6, Fig. 3

Quadrate outline with 7-8 'square' chambers in last whorl. Sutures slightly depressed. The wall is smooth and finely grained.

Reophax bilocularis FLINT 1899

1986 *Reophax bilocularis* Schröder, p. 42-43, pl. 14, figs. 8-13.

Reophax duplex GRZYBOWSKI 1896

1895 *Reophax duplex* Grzybowski, p. 58, pl. 8, figs. 23-25.

1988 *Reophax duplex* Kaminski *et al*, p. 187, pl. 2, fig. 15.

Reophax sp. 2

1990 *Reophax* sp. 2 Kuhnt, p. 324, pl. 3, figs. 7-9.

Reticulophragmium amplectens (GRZYBOWSKI 1898)

Plate 4, Figs. 1, 2

1989 *Reticulophragmium amplectens* King, p. 458, pl. 9.2, figs. 16-18.

1990 *Reticulophragmium amplectens* Kaminski *et al*, p. 369, pl. 6, figs. 4a-b.

1990 *Cyclammina (Reticulophragmium) amplectens* Charnock & Jones, p. 176, pl. 8, figs. 1-5.

1993 *Reticulophragmium amplectens* Kaminski & Geroch, p. 266, pl. 11, figs. 5-7c.

1994 *Reticulophragmium amplectens* Gradstein *et al.*, pl. 4, figs. 1-5, pl. 5, figs. 1-10

Stratigraphic Range: Eocene - Oligocene (RF2)

Reticulophragmium paupera (Chapman)

1994 *Reticulophragmium paupera* Gradstein *et al.*, pl. 4, figs.6-10.

Reticulophragmoides jarvisi (THALMANN 1932), emend GRADSTEIN & KAMINSKI 1989

1989 *Reticulophragmoides jarvisi* Gradstein & Kaminski, p. 81,83, pl. 7, figs. 1-8, text-fig. 4.

1990 *Reticulophragmoides jarvisi* Charnock & Jones, p. 177, pl. 8, figs. 12-13, pl. 19, fig. 4.

1994 *Reticulophragmoides jarvisi* Gradstein *et al.*, pl. 7, figs.10-11, pl. 11, fig. 6.

Stratigraphic Range: Late Paleocene - Early Oligocene (RF2)

Rhizammina indivisa BRADY 1884

1988 *Rhizammina indivisa* Kaminski *et al.*, p. 183, pl. 1, figs. 10-13.

1990 *Rhizammina indivisa* Kuhnt, p. 324, pl. 1. fig. 13.

1992 *Rhizammina indivisa* Morlotti and Kuhnt, p. 223, pl. 2. fig. 4.

Rzehakina minima (CUSHMAN & RENZ 1946)

Plate 3, Fig. 12

1988 *Rzehakina minima* Kaminski *et al*, p. 186, pl. 7, figs. 8-9.

1988 *Rzehakina minima* Jones, p. 148, pl. 2, fig. 2.

1990 *Rzehakina minima* Charnock& Jones, p. 159, pl. 3, figs. 3-4; pl. 14, fig. 15.

1994 *Rzehakina minima* Gradstein *et al.*, pl. 9, figs.18-20.

Stratigraphic Range: Campanian - Paleocene (RF2)

Rzehakina epigona (RZEHAK 1895)

Plate 3, Fig. 14

1988 *Rzehakina epigona* Kaminski *et al*, p. 186, pl. 7, figs. 6-7.

1990 *Rzehakina epigona* Charnock& Jones, p. 159, pl. 3, figs.1-2; pl. 14, fig. 14.

1994 *Rzehakina epigona* Gradstein *et al.*, pl. 9, figs.14-17.

Saccammina grzybowskii (SCHUBERT 1902)

1990 *Saccammina grzybowskii* Kuhnt, p. 325, pl. 2, fig. 1.

1993 *Saccammina grzybowskii* Kaminski & Geroch, p. 248. pl. 2, fig. 1a-4b.

Saccammina placenta (GRZYBOWSKI 1898)

1988 *Saccammina placenta* Kaminski *et al.*, p. 183, pl. 2, fig. 9.

1990 *Saccammina placenta* Kuhnt, p. 325, pl. 2, fig. 1.

1990 *Saccammina placenta* Charnock & Jones, p. 147, pl. 1, figs. 5-6; pl. 13, fig. 4.

Stratigraphic Range: Turonian?, Campanian - Late Oligocene/Early Miocene (RF2)

Saccammina sphaerica BRADY 1871

1990 *Saccammina sphaerica* Charnock & Jones, p. 147, pl. 1, fig. 7; pl. 13, fig. 5.

1994 *Saccammina sphaerica* Jones, p. 31, pl. 18, figs. 11-15, ?17.

Stratigraphic Range: Eocene - Recent (RF1)

         Eocene - Middle Miocene (RF2)

Depth Range: 150 - 5775 m (RF2)

Sigmoilopsis schlumbergeri (SILVESTRI 1904)

1986 *Sigmoilopsis schlumbergeri* Schröder, p. 56, pl. 21, fig. 9.

1989 *Sigmoilopsis schlumbergeri* King, p. 462, pl. 9.3, figs. 10, 11.

1995 *Sigmoilopsis schlumbergeri* Bender, p. 52, pl. 7, fig. 18 & pl. 12, fig. 7.

Stratigraphic Range: Miocene - Recent (RF1)

         Early Pliocene - Recent (RF3)

Depth Range: 28 - 1630 fm (RF1)

Spiroplectammina deperdita (D'ORBIGNY 1846)

1990 *Spiroplectammina (Spiroplectinella) deperdita* Charnock & Jones, p. 182, pl. 9, fig. 14; pl. 21, fig. 4.
Stratigraphic Range: Eocene - Early Oligocene (RF2)

Spiroplectammina navarroana CUSHMAN 1932, emend GRADSTEIN & KAMINSKI 1989
Plate 3, Fig. 5

1988 *Spiroplectammina navarroana* Kaminski *et al*, p. 193, pl. 7, figs. 13-15.

1989 *Spiroplectammina navarroana* Gradstein & Kaminski, p. 83,85. pl. 9. figs. 1-12, text-fig. 5.

1990 *Spiroplectammina (Spiroplectammina) navarroana* Charnock & Jones, p. 181, pl. 9, figs.
11-12; pl. 21, fig. 1.

1994 *Spiroplectammina navarroana* Gradstein *et al.*, pl. 1, fig. 12a,b, pl 11, figs. 11-12.
Stratigraphic Range: Santonian?, Campanian - Early Eocene (RF2)

Spiroplectammina spectabilis (GRZYBOWSKI 1898)
Plate 3, Figs. 1-3

1988 *Spiroplectammina spectabilis* Kaminski *et al.*, p. 193, pl. 7, figs, 16-18.

1990 *Spiroplectammina (Spiroplectinella) spectabilis* Charnock & Jones, p. 182-183, pl. 9, figs. 15-18.

1993 *Spiroplectammina spectabilis* Kaminski & Geroch, p. 267-268, pl. 12, figs. 4a-5c.
Stratigraphic Range: Campanian - Late Eocene (RF3)
        Santonian?, Campanian - Middle Eocene (RF2)

Spirosigmoilinella compressa MATSUNAGA 1955
Plate 3, Figs. 13, 15

1990 *Spirosigmoilinella compressa* Charnock & Jones, p. 159, pl. 3, figs. 5-6; pl. 14, fig. 16.

1990 *Spirosigmoilinella compressa* Kaminski *et al*, p. 367, pl. 4, figs. 1-2.
Stratigraphic Range: Middle/Late Eocene - Early Miocene (RF2)

Subreophax scalaris (GRZYBOWSKI 1896)

1988 *Subreophax scalaris* Kaminski *et al.*, p. 187, pl. 2, figs. 16-17.

1990 *Subreophax scalaris* Kuhnt, p. 326, pl. 3, figs. 4-5.

1992 *Subreophax scalaris* Morlotti and Kuhnt, p. 223, pl. 3, fig. 5.

Trochammina altiformis (CUSHMAN & RENZ 1946)
Plate 4, Fig. 11

1988 *Trochammina altiformis* Kaminski *et al*, p. 193, pl. 8, figs. 1a-2b.

Trochammina deformis GRZYBOWSKI 1898

1990 *Trochammina deformis* Kaminski *et al*, p. 369, pl. 7, figs. 1a-c.

Paratrochammina challengeri BRÖNNIMANN & WHITTAKER 1988

1986 *Trochammina* cf. *globigeriniformis* (Parker & Jones) Schröder, p. 52-53. pl.19, figs. 5-8.

1990 *Trochamminopsis challengeri* (Brönnimann & Whittaker) Charnock & Jones, p. 189. pl. 11, figs. 7-10. pl. 22. fig. 6.

1994 *Paratrochammina challengeri* Brönnimann & Whittaker, Jones, p. 41-42, pl. 35, fig. 10.
Stratigraphic range: Maastrichtian-Recent (RF1)
        Campanian - Early Oligocene (RF2)
Depth Range: 50 - 5029 m (RF2)

Trochammina ruthven-murrayi CUSHMAN & RENZ 1946
Plate 6, Figs. 10, 12

1988 *Trochammina ruthven-murrayi* Kaminski *et al*, p. 193, pl. 8, fig. 6a-c.

1989 *Trochammina ruthvenmurrayi* King, p. 460, pl. 9.3, figs. 3,4.

1990 *Trochammina (Ammoanita) ruthvenmurrayi* Charnock & Jones, p. 186, pl. 10, figs. 4-9; pl. 22, fig. 2.
Stratigraphic Range: Late Paleocene (RF3)

Trochammina **sp. 1**

1990 *Trochammina* sp. 1 Charnock & Jones, p. 187, pl. 11, figs. 4-6; pl. 22, fig. 5.

Stratigraphic Range: Campanian - Early/Middle Miocene (RF2)

Trochammina **sp. 2**

1990 *Trochammina* sp. 2 Charnock & Jones, p. 188, pl. 11, figs. 11-12; pl. 23, fig. 1.

Stratigraphic Range: Early - Middle Eocene (RF2)

Trochammina **sp. 3**

1990 *Trochammina* sp. 3 Charnock & Jones, p. 188, pl. 23, fig. 2.

Stratigraphic Range: Late Paleocene (rare) (RF2)

Trochammina **cf. sp. 4**

1990 *Trochammina* sp. 4 Charnock & Jones, p. 188, pl. 23, fig. 3.

Similar to Sp. 4 described by Charnock and Jones although this species was reported as being restricted to the Balder and Sele Formations.

Stratigraphic Range: Late Paleocene - Early Eocene (RF2)

Trochammina **sp. 5**

Plate 6, Figs. 4-5

Small, plano-convex with 7 chambers in final whorl. Sutures are curved and slightly depressed. Wall is finely grained.

Trochammina subvesicularis **HANZLIKOVA, in HOMOLA & HANZLIKOVA 1955**

Plate 6, Fig. 11

1990 *Trochammina (Insculptarenula) subvesicularis* Charnock & Jones, p. 187, pl. 10, figs. 10-12; pl. 22, fig. 3.

1994 *Trochammina* cf. *subvesicularis* Gradstein *et al.*, pl. 1. figs. 4-5?

May also contain species of *Ammonita ingerlisae* Gradstein and Kaminski (in press) (Gradstein pers. comm. 1997)

Stratigraphic Range: Late Paleocene, sporadic (caved? occurences in the Maastrichtian) (RF2)

Trochamminoides dubius **(GRZYBOWSKI 1898)**

Plate 6, Fig. 7

1988 *Trochamminoides dubius* Kaminski *et al.*, p. 191, pl. 4, figs. 16-17.

1990 *Trochamminoides dubius* Kuhnt, p. 326, pl. 5, fig. 9.

1996 *Trochamminoides dubius* Kaminski *et al.*, pl. 3, figs. 1-4.

Trochaminoides irregularis **(WHITE 1928)**

Plate 6, Fig. 8

1988 *Trochaminoides irregularis* Kaminski *et al.* , p. 191, pl. 4, fig. 18.

1990 *Trochaminoides irregularis* Kuhnt, p. 320, pl. 5, fig. 10.

Stratigraphic Range: Campanian - Late Paleocene (RF3)

Trochamminoides proteus **(KARRER 1866)**

1988 *Trochamminoides proteus* Kaminski *et al.*, p. 192, pl. 4, fig. 20.

1990 *Trochamminoides proteus* Kuhnt, p. 326, pl. 5, fig. 10.

1990 *Trochamminoides proteus* Charnock & Jones, p. 161, pl. 3, fig. 12; pl. 15, fig. 2.

Stratigraphic Range: Late Paleocene - Middle Eocene (rare) (RF2)

Trochamminoides subcoronatus **(GRZYBOWSKI 1896)**

1988 *Trochamminoides subcoronatus* Kaminski *et al.*, p. 192, pl. 4, fig. 20.

1992 *Trochamminoides subcoronatus* Morlotti and Kuhnt, p. 223, pl. 3, fig. 13.

Trochamminopsis pseudovesicularis (**KRASHENINNIKOV 1974**)

1990 *Trochamminopsis pseudovesicularis* Charnock & Jones, p. 189, pl. 22, fig. 7.

Stratigraphic Range: Eocene - Oligocene (RF2)

Depth Range: No previous record (South Atlantic range 278 - 3264 m) (RF2)

Veleroninoides scitulus (**BRADY 1881**)

1990 *Labrospira scitula* Charnock & Jones, p. 172, pl. 6, figs. 9-10; pl. 17, fig. 6.

1994 *Veleroninoides scitulus* Jones, p. 41, pl. 34, figs. 11-13.

Stratigraphic Range: Santonian? - Oligocene (RF2)

Depth Range: 600 - 4920 m (RF2)

Verneuilinoides aff. *polystrophus* (**REUSS 1846**)

1988 *Verneuilinoides polystrophus* Kaminski et al., p. 194, pl. 8, fig. 8.

Wider and not so tapered as *V. polystrophus*.

Calcareous benthic foraminifers

Alabiminoides exiguus (**BRADY 1884**)

1964 *Epistominella exigua* Feyling-Hanssen, p. 338, pl. 18, figs. 19, 20.

1994 *Alabiminoides exiguus* Jones p. 103, pl. 103, figs. 13-14.

Ammonia beccarii (**LINNÉ 1758**)

Plate 1, Fig. 6

1980 *Ammonia beccarii* Doppert, pl. 1, fig. 1 a, b, c.

1989 *Ammonia beccarii* Funnell, p. 566, pl. 12.1, figs. 1-3.

Astacolus hyalacrulus **LOEBLICH & TAPPAN 1953**

1953 *Astaculus hyalacrulus* Loeblich & Tappan, p. 52, pl. 9, figs. 1-4.

Astacolus reniforme (**D'ORBIGNY 1846**)

1994 *Vaginulinopsis renifomis* Jones, p. 81, pl. 70, fig. 3.

Biloculinella globula (**BORNEMANN 1855**)

1967 *Biloculinella globula* Todd & Low, p. A20, pl. 2. fig. 14.

Bolivina antiqua **D'ORBIGNY 1846**

1950b *Bolivina antiqua* Van Voorthuysen, p. 62, pl. 2, fig. 23.

1965 *Bolivina antiqua* Grossheide & Trunko, p. 94, pl. 12, figs. 4a, b.

1989 *Bolivina antiqua* King, p. 467, pl. 9.4, fig. 22.

Stratigraphic Range: Late Oligocene - basal Late Miocene (RF3)

Brizalina earlandi (**PARR 1950**)

1953 *Bolivina pseudopunctata* Höglund 1949 Loeblich and Tappan, p. 111, pl. 20. figs. 13-14.

1957 *Bolivina punctata* d'Orbigny 1848, AGIP Mineraria pl. 30. fig. 9.

1994 *Brizalina earlandi* (Parr 1950) Jones, p. 57, pl. 52, figs. 18-19.

Brizalina subaenariensis var. *mexicana* **BRADY 1881**

1952 *Brizalina aenariensis* Foraminiferi Padeni pl. 28, fig. 9.

1994 *Brizalina subaenariensis* var. *mexicana* Jones p. 58, pl. 53, figs. 10-11.

Bucella frigida (CUSHMAN 1921)

Plate 1, Fig. 7

1953 *Bucella frigida* Loeblich & Tappan, p. 115, pl. 22, figs. 2-3.

1971 *Bucella frigida* Knudsen, p. 253, pl. 8, figs. 12-14.

1989 *Bucella frigida* King, p. 467, pl. 9.4, figs. 26-27.

1991 *Bucella frigida* Thies, p. 35, pl. 19, figs. 6a-d & pl. 20, figs. 5-6.

Stratigraphic Range: Early Pliocene?, Late Pliocene - Recent (RF3)

Depth Range: 13 - 220 fm (RF1)

Bucella tenerrima (BANDY 1950)

1971 *Bucella tenerrima* Knudsen, p. 254, pl. 8, figs. 15-17.

1989 *Bucella tenerrima* King, p. 468, pl. 9.4, figs. 28, 29.

Stratigraphic Range: Late Pliocene - Pleistocene (living in Arctic Areas) (RF3)

Bulimina aculeata D'ORBIGNY 1826

Plate 2, Figs. 3-4

1980 *Bulimina aculeata* Doppert, pl. 5, fig. 1.

1986 *Bulimina aculeata* Morkhoven *et al* . p. 31. pl. 7.

Stratigraphic Range: Miocene - Recent (RF1)

Depth Range: 1000 - 2740 fm (RF1)

Bulimina alazanensis CUSHMAN 1927

1989 *Bulimina alazanensis* Jenkins *et al* , p. 550, pl. 11.1, figs. 13-14.

Bulimina elongata D'ORBIGNY 1846

1942 *Bulimina elongata* Ten Dam & Reinhold p. 80, pl. 5, fig. 11.

1989 *Bulimina elongata* King, p. 468, pl. 9.5, fig. 3.

1992 *Bulimina elongata* Seidenkrantz, pl. 2, fig. 4.

Stratigraphic Range: Miocene - Recent (RF1)

                       Late Oligocene - basal Late Miocene (RF3)

Depth Range: 630 - 1425 fm (Atlantic) (RF1)

Bulimina gibba FORNASINI 1902

Plate 2, Fig. 2

1946 *Bulimina gibba* Cushman, p. 125, pl. 28, figs. 37-38, pl. 29, figs. 1-5.

1989 *Bulimina gibba* King, p. 468, pl. 9.5, fig. 4.

Stratigraphic Range: Early Pliocene?, Late Pliocene - Recent (RF3)

Bulimina marginata D'ORBIGNY 1826

Plate 2, Figs. 7-8

1971 *Bulimina marginata* Knudsen, p. 235, pl. 6, figs. 17-20.

1989 *Bulimina marginata* King, p. 468, pl. 9.5, fig. 5.

1992 *Bulimina marginata* Struck, p. 22, pl. 5, fig. 5.

1994 *Bulimina marginata* Austin & Sejrup, pl. 1, fig. 11.

Stratigraphic Range: Late Miocene - Recent (RF1)

                       Late Pliocene - Recent (RF3)

Depth Range: to 1630 fm (temperate) (RF1)

Cancris auriculus (FICHTEL & MOLL 1803)

1942 *Cancris auriculus* Ten Dam & Reinhold, p. 89, pl. 6, fig. 8.

1965 *Cancris auriculus* Grossheide & Trunko, p. 142-143, pl. 14, figs. 1a, b.

1989 *Cancris auriculus* King, p. 470, pl. 9.5, figs. 12-13.

Stratigraphic Range: Miocene - Recent (RF1)

Early Miocene - Late Miocene, Early Pliocene? (RF3)

Depth Range: Littoral to 500 fm (RF1)

Cassidulina crassa D'ORBIGNY 1839

1958 *Cassidulina crassa* van Voorthuysen, p. 17, pl. 4, figs. 61 a, b, c.

1964 *Cassidulina crassa* Feyling-Hanssen, p. 322, pl. 16, figs. 11-13.

1971 *Cassidulina crassa* Knudsen, p. 245, pl. 7, figs. 18-19.

Stratigraphic Range: Miocene - Recent (RF1)

Cassidulina laevigata D'ORBIGNY 1826

Plate 1, Fig. 9

1981 *Cassidulina laevigata* Sejrup *et al* ., p.290, pl. 1, fig. 5.

1988 *Cassidulina laevigata* Mackensen & Hald, p. 17, pl. 1, figs. 1-7.

1989 *Cassidulina laevigata* King, p. 471, pl. 9.5, fig. 18.

1994 *Cassidulina laevigata* Austin & Sejrup, pl. 1, fig. 8.

Stratigraphic Range: Middle Miocene - Recent (RF1)

Late Miocene - Recent (RF3)

Cassidulina norcrossi CUSHMAN 1933

1953 *Cassidulina norcrossi* Loeblich & Tappan, p. 120, pl. 24, fig. 2.

1971 *Islandiella norcrossi* Knudsen, p. 248, pl. 8. figs. 1-2.

Cassidulina obtusa WILLIAMSON 1858

1980 *Cassidulina obtusa* Sejrup & Guilbaut, p. 81. figs. 2A-E

1994 *Cassidulina obtusa* Jones, p. 60. pl. 54. fig. 5.

Cassidulina reniforme NÖRVANG 1945

1980 *Cassidulina reniforme* Sejrup & Guilbaut, p. 79, pl. 2.

1992 *Cassidulina reniforme* Wollenburg, p. 55, pl. 15, figs. 8,11.

Cassidulina teretis TAPPAN 1951

Plate 1, Fig. 8

1971 *Islandiella teretis* Knudsen, p. 249 pl. 8, figs. 3-6.

1988 *Cassidulina teretis* Mackensen & Hald, p.17, pl. 1, figs. 8-15.

1992 *Cassidulina teretis* Seidenkrantz, pl. 1, fig. 7; pl. 3, fig. 13.

1992 *Cassidulina teretis* Struck, p. 18, pl. 5, fig. 1.

Stratigraphic Range: Pliocene - Recent (RF1)

Cibicides dutemplei (D'ORBIGNY 1846)

1965 *Cibicides dutemplei* Grossheide & Trunko, p. 158, pl. 14, figs. 11a-c.

1986 *Cibicides dutemplei* Morkhoven *et al* ., p.112, pl. 35.

Cibicides grossus (TEN DAM & REINHOLD 1941)

Plate 1, Figs. 10-11

1950b *Cibicides grossa* Van Voorthuysen p. 65, pl. 3, figs. 12,14.

1982 *Cibicides grossa* Knudsen, p. 106 pl. 2, figs. 9-11 & 14-16.

1989 *Cibicides grossus* King, p. 471, pl. 9.6, figs. 12-13.

1992 *Cibicides grossus* Seidenkrantz, pl. 3, figs. 5-7.

Stratigraphic Range: Index species for Late Pliocene & earliest Pleistocene in circum-Arctic
seas. Recorded from North Sea Basin, Norwegian Sea, Greenland Sea, Canadian Arctic & Siberia.
(RF3)

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Cibicides lobatulus (WALKER & JACOB 1798)

Plate 1, Fig. 12

1967 *Cibicides lobatulus* Todd & Low p. A34, pl. 5, figs. 1,2,4.

1971 *Cibicides lobatulus* Knudsen, p. 260, pl. 9, figs. 9-14.

1992 *Cibicides lobatulus* Hald & Steinsund, p. 360, pl. 1, figs. 7-8.

1991 *Cibicides lobatulus* Thies, p. 31, pl. 17, figs. 4a-d; pl. 18, figs. 1-20.

Stratigraphic Range: Middle Miocene - Recent (RF1)

Depth Range: Shallow water to 3000 fm (RF1)

Cibicides refulgens DE MONTFORT 1808

1958 *Cibicides refulgens* van Voorthuysen, p. 22, pl. 8, figs. 82a-c.

1992 *Cibicides refulgens* Seidenkrantz, pl. 1, fig. 9; pl. 3, fig. 4.

1994 *Cibicides refulgens* Jones, p. 97, pl. 92, figs. 7-9.

Stratigraphic Range: Late Miocene - Recent (RF1)

Depth Range: 50 - 2400 fm (RF1)

Cibicides scaldisiensis (TEN DAM & REINHOLD 1941)

1941 *Cibicides scaldisiensis* Ten Dam & Reinhold p. 62, pl. 5, fig. 6.

1992 *Cibicides scaldisiensis* Seidenkrantz, pl. 3, figs. 8-9.

Cibicides sulzensis (HERRMANN 1917)

1965 *Cibicides sulzensis* Spiegler, p. 474, pl. 22, fig. 13.

Stratigraphic Range: Late Eocene - Early Rupelian

Cibicidoides limbosuturalis (VAN VOORTHUYSEN 1950)

1950 *Cibicides cookei* var. *limbato-suturalis*, van Voorthuysen, p. 65. textfigs. 5a-f.

1989 *Cibicidoides limbosuturalis*, King, p. 472, pl. 9.6. figs. 8-9

Cibicidoides pachyderma (RZEHAK 1886)

1986 *Cibicidoides pachyderma* Morkhoven *et al*, p. 68-71.

1994 *Cibicidoides pachyderma* Jones, p. 98, pl. 94, fig. 9.

Cribroelphidium bartletti CUSHMAN 1933

Plate 1, Fig. 1

1953 *Elphidium bartletti* Loeblich & Tappan p. 96, pl. 18, figs. 10-14.

1964 *Elphidium bartletti* Feyling-Hanssen, p. 343, pl. 21, figs. 1-2.

1971 *Elphidium bartletti* Knudsen, p. 11, figs. 6-9; pl. 20, figs. 1-4.

1989 *Cribroelphidium bartletti* King, p. 472, pl. 9.6, figs. 14-15.

Stratigraphic Range: Pleistocene (living in Arctic & Subarctic areas) (RF2)

Cribrononion incertum (WILLIAMSON 1858)

Plate 1, Fig. 5

1971 *Elphidium incertum* Knudsen, p. 277, pl. 12, figs. 11-12; pl. 21, figs. 8-9.

1994 *Cribrononion incertum* Jones p. 108, pl. 109, fig. 23.

Dentalina baggi GALLOWAY & WISSLER 1927

1953 *Dentalina baggi* Loeblich & Tappan p. 54, pl. 9, figs. 10-15.

1967 *Dentalina baggi* Todd & Low, p. A22, pl. 3, figs. 10-11.

1971 *Dentalina baggi* Knudsen, p. 199, pl. 3, fig. 1.

Dentalina subsoluta (CUSHMAN 1923)

1971 *Dentalina subsoluta* Knudsen, p. 201-202, pl. 3, fig. 5.

1994 *Dentalina subsoluta* Jones, p. 73, pl. 62, figs. 13-16.

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Ehrenbergina variabilis (TRUNKO 1965)

1965 *Ehrenbergina variabilis* Grossheide & Trunko, p. 124-126, pl. 13, figs. 1a, b.

Elphidiella arctica (PARKER & JONES)

1953 *Elphidiella arctica* Loeblich & Tappan, p. 106, pl. 20, figs. 1-3.

1967 *Elphidiella arctica* Todd & Low, p. A34, pl. 4, fig. 15.

1971 *Elphidiella arctica* Knudsen, p. 284, pl. 14, fig. 1.

Depth Range: 7 - 210 fm (Atlantic) (RF1)

Elphidiella hannai (CUSHMAN & GRANT 1927)

1989 *Elphidiella hannai* King, p. 474-475, pl. 9.6, figs. 16-17.

1992 *Elphidiella hannai* Seidenkrantz, pl. 1, fig. 5 & pl. 2, fig. 9.

Elphidium albiumbilicatum (WEISS 1954)

1971 *Elphidium albiumbilicatum* Knudsen, p. 268, pl. 10, figs. 15-19; pl. 19, figs. 4-8.

1989 *Elphidium albiumbilicatum* King, p. 475, pl. 9.6, fig. 19.

Stratigraphic Range: Pleistocene and Recent (RF3)

Elphidium crispum (LINNÉ 1758)

1958 *Elphidium crispum* van Voorthuysen, p. 24, pl. 9, figs. 93a-c.

1994 *Elphidium crispum* Jones, p. 109, pl. 110, figs. 6-7.

Stratigraphic Range: Miocene - Recent (RF1)

Depth Range: shallow water (to 355 fm) (RF1)

Elphidium excavatum (TERQUEM 1875), forma *clavata* CUSHMAN 1930

Plate 1, Fig. 3

1976 *E. excavatum* forma *clavata* Feyling-Hanssen, p. 92, pl. 8, figs. 13-14.

1981 *Elphidium excavatum* Sejrup *et al* . p. 293, pl. 1, fig. 10.

1984 *E. excavatum* forma *clavata* Knudsen, p. 103, pl. 4, figs. 12-13.

1991 *Elphidium excavatum* Thies, p. 35, pl. 19, fig. 5.

Stratigraphic Range: Early Pliocene - Recent (RF3)

Elphidium groenlandicum CUSHMAN 1923

1971 *Elphidium groenlandicum* Knudsen, p. 275, pl. 12, figs. 1-8.

1989 *Elphidium groenlandicum* King, p. 475, pl. 9.6, figs. 25-26.

1992 *Elphidium groenlandicum* Seidenkrantz, pl. 2, fig. 6.

Stratigraphic Range: Early Pliocene?, Late Pliocene & Pleistocene (living in Arctic areas) (RF3)

Elphidium gunteri COLE 1931

1971 *Elphidium gunteri* Knudsen, p. 277, pl. 12, figs. 9,10; pl. 21, figs. 4-7.

Elphidium macellum (FICHTEL & MOLL 1798)

Plate 1, Fig. 4

1964 *Elphidium macellum* Feyling-Hanssen, p. 347, pl. 20, fig. 16.

1971 *Elphidium macellum* Knudsen, p. 278, pl. 12, figs. 13-14; pl. 22, figs. 1-4.

1994 *Elphidium macellum* Austin & Sejrup, pl. 2, fig. 8.

Stratigraphic Range: Miocene - Recent (RF1)

Depth Range: Shallow water (low latitudes) (RF1)

Elphidium magellanicum HERON-ALLEN & EARLAND 1932

1971 *Elphidium magellanicum* Knudsen, p. 279, pl. 12, figs. 15-16.

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Elphidium margaritaceum (CUSHMAN 1930)

1971 *Elphidium margaritaceum* Knudsen, *et al* , p. 279, pl.13, figs. 1,2; pl. 22, figs. 5-8.

Elphidium oregonense CUSHMAN & GRANT 1927

1953 *Elphidium oregonense* Loeblich & Tappan p. 103, pl. 18, figs. 1-3.

1967 *Elphidium oregonense* Todd & Low p. A34, pl. 4, fig. 18.

1989 *Elphidium oregonense* King, p. 475, pl. 9.6, fig. 18.

Stratigraphic Range: Early Pleistocene (RF3)

Elphidium pseudolessonii TEN DAM & REINHOLD 1941

1941 *Elphidium pseudolessonii* Ten Dam & Reinhold p. 53, pl. 3, fig. 10.

1958 *Elphidium pseudolessonii* van Voorthuysen p. 25, pl. 9, fig. 97.

1980 *Elphidium pseudolessonii* Doppert, pl. 2, figs. 3 a-b.

Elphidium subarcticum CUSHMAN 1944

1953 *Elphidium subarcticum* Loeblich & Tappan p. 105, pl. 19, figs. 5-7.

1964 *Elphidium subarcticum* Feyling-Hanssen, p. 347, pl. 20, figs. 17-19.

1971 *Elphidium subarcticum* Knudsen, p. 280, pl. 13, figs. 3-7; pl. 22, fig. 9.

1989 *Elphidium subarcticum* King, p. 476, pl. 9.7, fig. 1.

Stratigraphic Range: Pleistocene - Recent (RF3)

Elphidium umbilicatum (WILLIAMSON 1858)

1971 *Elphidium umbilicatum* Knudsen, p. 281, pl. 13, figs. 8-11; pl. 23, figs. 1-4.

Elphidium ustulatum TODD 1957

Plate 1, Fig. 2

1971 *Elphidium ustulatum* Knudsen, p. 283, pl. 13, figs. 12-13; pl. 23, figs. 5-7.

1989 *Elphidium ustulatum* King, p. 476, pl. 9.7, fig. 6.

1992 *Elphidium ustulatum* Seidenkrantz, pl. 2, fig. 7.

Stratigraphic Range: Pleistocene (RF3)

Fissurina laevigata REUSS 1850

1964 *Fissurina laevigata* Feyling-Hanssen, p. 314, pl. 15, figs. 17-18.

1994 *Fissurina laevigata* Jones, p. 113, pl. 114, fig. 8.

Stratigraphic Range: Miocene - Recent (RF1)

Depth Range: 2 - 3125 fm (RF1)

Fissurina marginata (MONTAGU 1803)

1953 *Fissurina marginata* Loeblich & Tappan p. 77, pl. 14, figs. 6-9.

1964 *Fissurina marginata* (Walker & Boys) Feyling-Hanssen, p. 315, pl. 15, fig. 22.

1992 *Fissurina marginata* Wollenburg, p. 50, pl. 13. fig. 10.

Fissurina orbignyana SEGUENZA 1862

1941 *Lagena orbignyana* Ten Dam & Reinhold p. 48, pl. 2, figs. 9; pl. 6, fig. 7.

1950a *Fissurina orbignyana* Van Voorthuysen p. 36, pl. 1, fig. 4.

1971 *Fissurina orbignyana* Knudsen, p. 230, pl. 6, fig. 8.

1994 *Fissurina orbignyana* Jones, p. 68, pl. 59, fig. 18.

Stratigraphic Range: Miocene - Recent (RF1)

Florilus aequalis (CLODIUS 1922)

1974 *Florilus aequalis* Spiegler, p. 68, pl. 2, figs. 15-16.

Florilus boueanus (D'ORBIGNY 1846)

1965 *Nonion boueanum* Grossheide & Trunko, p. 129, pl. 13, fig. 4.

1980 *Florilus boueanus* Doppert, pl. 9, fig. 7 a-b; pl. 16, figs. 1 a-b.

1989 *Florilus boueanus* King, p. 476, pl. 9.7, figs. 7,8.

Stratigraphic Range: Late Oligocene - Early Pliocene (RF3)

Fursenkoina fusiformis (WILLIAMSON 1858)

1964 *Virgulina fusiformis* Feyling-Hanssen, p. 307, pl. 14, figs. 15-18.

1991 *Fursenkoina fusiformis* Scott &Vilks p. 30. pl. 2, fig 8. pl. 4. fig. 11

Glandulina laevigata D'ORBIGNY 1826

1953 *Glandulina laevigata* Loeblich & Tappan p. 81, pl. 16, figs. 2-5.

1965 *Glandulina laevigata* Grossheide & Trunko, p. 89, pl. 10, fig. 12.

1971 *Glandulina laevigata* Knudsen, p. 220, pl. 5, fig. 12.

Globocassidulina subglobosa (BRADY 1844)

1980 *Globocassidulina subglobosa* Doppert, pl. 10, fig. 5 a-b.

1992 *Globocassidulina subglobosa* Struck, p. 19, pl. 1, fig. 7.

1994 *Globocassidulina subglobosa* Jones p. 60, pl. 54, fig. 17

Stratigraphic Range: Oligocene - Recent (RF1)

Depth Range: 12 - 2950 fm (RF1)

Guttulina glacialis (CUSHMAN & OZAWA 1930)

1971 *Guttulina glacialis* Knudsen, p. 213, pl. 4, figs. 11-13.

Gyroidina soldanii girardana (REUSS 1851)

1942 *Gyroidina giradana* Ten Dam & Reinhold p. 86, pl. 6, fig. 5.

1965 *Gyroidina soldanii giradana* Grossheide & Trunko, p. 136.

1989 *Gyroidina soldanii giradana* King. p. 478, pl. 9.7, figs. 15-16.

1995 *Gyroidina giradana* Gradstein *et al* . pl. 15 figs. 1a.b, pl. 17, figs. 17-18.

Gyroidina soldanii mamillata (ANDREAE 1884)

1942 *Gyroidina mamillata* Ten Dam & Reinhold p. 87, pl. 6, fig. 6.

1989 *Gyroidina soldanii mamillata* King, p. 478, pl. 9.7, pl. 17.

Stratigraphic Range: Early Oligocene - early Late Oligocene (RF3)

Haynesina orbicularis (BRADY 1881)

1964 *Protelphidium orbiculare* Feyling-Hanssen, p. 349, pl. 21, fig. 3.

1980 *Protelphidium orbiculare* Doppert, pl. 4, figs. 2 a-b.

1994 *Haynesina orbicularis* Jones, p. 108, pl. 109, figs. 20-21.

Hoeglundina elegans (D'ORBIGNY 1826)

1964 *Hoeglundina elegans* Feyling-Hanssen, p. 342, pl. 20, figs. 1-6.

1980 *Hoeglundina elegans* Doppert, pl. 11, figs. 2 a, b, c.

Stratigraphic Range: Late Eocene - Recent (RF1)

Hyalinea balthica (SCHROETER 1783)

1964 *Hyalinea balthica* Feyling-Hanssen, p. 351, pl. 21, figs. 14-16.

1971 *Hyalinea balthica* Knudsen, p. 259, pl. 9, figs. 7-8.

1989 *Hyalinea balthica* King, p. 478, pl. 9.7, fig. 21.

Stratigraphic Range: Middle? Miocene - Recent (RF1)

                              Pleistocene - Recent (RF3)

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Islandiella helaenae **FEYLING-HANSSEN & BUZAS 1976**

1976 *Islandiella helaenae* Feyling-Hanssen & Buzas, p. 155, text-figs. 1-4

1989 *Islandiella helaenae* King, p. 478, pl. 9.7, fig. 22.

Stratigraphic Range: Late Pliocene - Pleistocene

                    (living in Arctic Areas) (RF3)

Islandiella islandica **(NÖRVANG 1945)**

1971 *Islandiella islandica* Knudsen, p. 247, pl. 7, figs. 22-25.

1989 *Islandiella islandica* King, p. 478-479, pl. 9.7, figs. 23-24.

Stratigraphic Range: Late Pliocene - Recent (RF3)

Islandiella norcrossi **(CUSHMAN 1933)**

1967 *Cassidulina norcrossi* Todd & Low p. A37, pl. 5, fig. 11.

1964 *Islandiella norcrossi* Feyling-Hanssen, p. 325, pl. 16, fig. 20; pl. 17, fig. 1.

1971 *Islandiella norcrossi* Knudsen, p. 248, pl. 8, figs. 1-2.

1992 *Islandiella norcrossi* Seidenkrantz, pl. 1, fig. 4.

Lagena sulcata **(WALKER & JACOB 1798)**

1942 *Lagena sulcata* Ten Dam & Reinhold p. 70, pl. 3, fig. 14.

1958 *Lagena sulcata* van Voorthuysen, p. 9, pl. 2, figs. 19 a, b, c.

1965 *Lagena sulcata* Grossheide & Trunko, p. 73, pl. 8, figs. 3a, b.

1994 *Lagena sulcata* Jones p. 64, pl. 57, figs. 25-27, 33-34.

Stratigraphic Range: Miocene - Recent (RF1)

Lenticulina gibba **(D'ORBIGNY 1839)**

1964 *Lenticulina (Robulus)* cf. *gibba* Feyling-Hanssen, p. 278, pl. 9, fig. 11.

1994 *Lenticulina gibba* Jones p. 81, pl. 69, figs. 8-9.

Depth Range: <500 fm (RF1)

Lenticulina thalmanni **(HESSLAND 1943)**

Plate 2, Fig. 15

1971 *Lenticulina thalmanni* Knudsen, p. 203, pl. 3, fig. 6.

1994 *Lenticulina thalmanni* Jones, p. 81, pl. 69, fig. 13.

Depth Range: 345 - 2200 fm (RF1)

Melonis barleeanum **(WILLIAMSON 1858)**

1964 *Melonis zaandami* (Voorthuysen) Loeblich & Tappan, p. 761, pl. 627, figs. 2-3.

1971 *Nonion barleeanum* Knudsen, p. 261, pl. 9, figs. 15-18.

1991 *Melonis barleeanum* Thies p. 33, pl. 19, figs. 3a-d.

1992 *Melonis barleeanum* Hald & Steinsund p. 360, pl. 2, fig. 4.

Stratigraphic Range: Pliocene - Recent (in North Sea) (RF2)

Miliolinella subrotunda **(MONTAGU 1803)**

Plate 2, Fig. 11

1971 *Miliolinella subrotunda* Knudsen, p. 197, pl. 2, figs. 10-12.

1991 *Miliolinella subrotunda* Thies, p. 26, pl. 14, fig. 2a-d.

Depth Range: 28 - 150 fm (Southern Ocean, Pacific) (RF1)

Nonion auricula **(HERON-ALLEN & EARLAND 1930)**

1971 *Nonion auricula* Knudsen, p. 265, pl. 10, figs. 7-9.

Nonion orbiculare **(BRADY)**

1953 *Elphidium orbiculare* Loeblich & Tappan p. 102, pl. 19, figs. 1-4.

1950a *Nonion orbicularis* Van Voorthuysen p. 41, pl. 3, fig. 5.

1971 *Protoelphidium orbiculare* Knudsen, p. 289, pl. 14, figs. 8-11; pl. 24, figs. 6-8.

1992 *Nonion orbiculare* Seidenkrantz, pl. 2, fig. 10.

Nonion umbilicatulum **(WALKER & JACOB 1798)**

1971 *Nonion umbilicatulum* Knudsen, p. 263, pl. 10, figs. 3-4; pl. 19, figs. 2-3.

Nuttalides truempyi **(NUTTALL 1930)**

1986 *Nuttalides truempyi* van Morkhoven *et al*, p. 288-295, pls. 96A-D.

Oolina borealis **LOEBLICH & TAPPAN 1954**

Plate 2, Fig. 9

1967 *Oolina borealis* Todd & Low p. A28, pl. 3, fig. 34.

1971 *Oolina borealis* Knudsen, p. 223, pl. 6, fig. 2; pl. 17, figs. 2-4.

Oolina globosa **(MONTAGU 1803)**

1971 *Oolina globosa* Knudsen, p. 224.

1994 *Oolina globosa* Jones, p. 62, pl. 56, figs. 15-16.

Sratigraphic Range: Miocene? - Recent (RF1)

Oolina hexagona **(WILLIAMSON 1848)**

1971 *Oolina hexagona* Knudsen, p. 224-225, pl. 17, fig. 6.

1994 *Oolina hexagona* Jones, p. 66, pl. 58, fig. 33.

Stratigraphic Range: Pliocene - Recent (RF1)

Oolina melo **D'ORBIGNY 1839**

Plate 2, Fig. 10

1953 *Oolina melo* Loeblich & Tappan p. 71, pl. 12, figs. 8-15.

1967 *Oolina melo* Todd & Low p. A29, pl. 3, fig. 27.

1964 *Oolina melo* Feyling-Hanssen, p. 312, pl. 15, figs. 6-7.

1971 *Oolina melo* Knudsen, p. 226, pl. 6, fig. 5; pl. 17, fig. 9.

1989 *Oolina melo* Osterman & Qvale, pl. 1. fig. 1.

Oolina williamsoni **(ALCOCK 1865)**

Plate 2, Fig. 13

1967 *Oolina williamsoni* Todd & Low p. A29, pl. 3, fig. 29.

1964 *Oolina williamsoni* Feyling-Hanssen, p. 312, pl. 15, fig. 8.

1971 *Oolina williamsoni* Knudsen, p. 227, pl. 18, figs. 1-2.

Oridorsalis umbonata **(REUSS 1851)**

1994 *Oridorsalis umbonata* Jones, p. 99, pl. 95. fig. 11.

Stratigraphic Range: Oligocene - Recent (RF1)

Depth Range: 166 - 3125 fm (RF1)

Parafissurina lateralis **(CUSHMAN), forma** *carinata* **(BUCHNER)**

1964 *Parafissurina lateralis* , f. *carinata* Feyling-Hanssen, p. 316, pl. 15, figs. 25-26.

1971 *Parafissurina lateralis* (Cushman), forma *carinata* (Buchner) Knudsen p. 233, pl. 6, figs.12-13.

Plectofrondicularia advena **(CUSHMAN 1923)**

1974 *Plectofrondicularia advena* Spiegler, p. 59, pl. 2, fig. 9.

1989 *Plectofrondicularia advena* King, p. 466, pl. 9.4, fig. 9.

1994 *Plectofrondicularia advena* Jones, p. 78, pl. 66, figs. 8-12.

Stratigraphic Range: Late Miocene - early Late Pliocene (RF3)

Depth Range: 129 - 1240 fm (RF1)

Procerolagena gracillima (EHRENBERG 1844)

1967 *Lagena elongata* Todd & Low p. A24, pl. 3, fig. 22.

1964 *Lagena elongata* Feyling-Hanssen, p. 287, pl. 11, fig. 9.

1994 *Procerolagena gracillima* Jones, p. 62, pl. 56, figs. 19-22, 24-29.

Pullenia bulloides (D'ORBIGNY 1846)

1964 *Pullenia bulloides* Feyling-Hanssen, p. 333, pl. 18, figs. 1-2.

1971 *Pullenia bulloides* Knudsen, p. 266, pl. 10, figs. 13-14.

1980 *Pullenia bulloides* Doppert, pl. 13, figs. 2 a-b.

Stratigraphic Range: Oligocene - Recent (RF1)

Depth Range: 300 - 2750 fm (RF1)

Pullenia quinqueloba (REUSS 1851)

1958 *Pullenia quinqueloba* van Voorthuysen, p. 18, pl. 5, fig. 64.

1994 *Pullenia quinqueloba* Jones, p. 92, pl. 84, figs. 14-15.

Stratigraphic Range: Oligocene - Recent (RF1)

Depth Range: 20 - 2750 fm (RF1)

Pyrgo rotalaria LOEBLICH & TAPPAN 1953

1953 *Pyrgo rotalaria* Loeblich & Tappan, p. 47-48, pl. 6, figs. 5-6.

1991 *Pyrgo rotalaria* Thies, p. 27-28, pl. 14, fig. 4a-c; pl. 15, figs. 1-21.

Pyrgo williamsoni (SILVESTRI 1923)

1953 *Pyrgo williamsoni* Loeblich & Tappan p. 48, pl. 6, figs. 1-4.

1964 *Pyrgo williamsoni* Feyling-Hanssen, p. 264, pl. 7, figs. 5-6; pl. 8, figs. 3-5.

1971 *Pyrgo williamsoni* Knudsen, p. 196, pl. 2, figs. 8-9; pl. 15, fig. 9.

1989 *Pyrgo williamsoni* Osterman & Qvale, pl. 1, fig. 11.

Quinqueloculina seminulum (LINNÉ 1758)
Plate 2, Fig. 12

1967 *Quinqueloculina seminulum* Todd & Low p. A19, pl. 2, fig. 19.

1964 *Quinqueloculina seminulum* Feyling-Hanssen, p. 251, pl. 6, fig. 1.

1971 *Quinqueloculina seminulum* Knudsen, p. 194, pl. 1, figs. 18-20.

1994 *Quinqueloculina seminulum* Jones, p. 21, pl. 5, fig. 6.

Stratigraphic Range: Miocene - Recent (RF1)

Depth Range: shallow water to 3000 fm (RF1)

Quinqueloculina stalkeri LOEBLICH & TAPPAN 1953

1953 *Quinqueloculina stalkeri* Loeblich & Tappan p. 40, pl. 5, figs. 5-9.

1967 *Quinqueloculina stalkeri* Todd & Low p. A19, pl. 2, fig. 17.

1964 *Quinqueloculina stalkeri* Feyling-Hanssen, p. 252, pl. 4, fig. 12.

1971 *Quinqueloculina stalkeri* Knudsen, p. 194, pl. 2, figs. 1-3.

Rosalina vilardeboana D'ORBIGNY 1939

1964 *Rosalina vilardeboana* Feyling-Hanssen, p. 336, pl. 18, figs. 10, 11.

1971 *Rosalina vilardeboana* Knudsen, p. 256, pl. 8, figs. 18-20.

1994 *Rosalina vilardeboana* Jones, p. 93, pl. 86, fig. 9.

Stratigraphic Range: Middle Miocene - Recent (RF1)

Rotaliatina bulimoides (REUSS 1851)

1942 *Rotaliatina bulimoides* Ten Dam & Reinhold p. 87, pl. 6, fig. 4.

1989 *Rotaliatina bulimoides* King, p. 480, pl. 9.8, fig. 15.

Stratigraphic Range: Early Oligocene (RF3)

Sphaeroidina bulloides DESHAYES 1832

Plate 2, Fig. 16

1942 *Sphaeroidina bulloides* (D'Orbigny 1826) Ten Dam & Reinhold p. 95, pl. 7, fig. 6.

1980 *Sphaeroidina bulloides* (D'Orbigny 1826) Doppert, pl. 16, fig. 2; pl. 20, fig. 5.

1986 *Sphaeroidina bulloides* (D'Orbigny 1826) Morkhoven et al. p. 80, pl. 24.

1994 *Sphaeroidina bulloides* Jones, p. 91, pl. 84, figs. 1-5. ?6-7.

Stratigraphic Range: Oligocene - Recent (RF1)

Depth Range: 85 - 2600 fm (RF1)

Stainforthia loeblichi (FEYLING-HANSSEN 1954)

1964 *Virgulina loeblichi* Feyling-Hanssen, p. 308, pl. 14, figs. 12-14.

1971 *Virgulina loeblichi* Knudsen, p. 238, pl. 7, figs. 1-5.

1989 *Stainforthia loeblichi* Osterman & Qvale, pl. 2. fig. 14.

Stainforthia schreibersiana (CZJZEK 1847)

1964 *Virgulina schreibersiana* Feyling-Hanssen, p. 309, pl. 14, figs. 19-21.

1971 *Virgulina schreibersiana* Knudsen, p. 240, pl. 7, figs. 6-8.

1980 *Stainforthia schreibersiana* Doppert, pl. 21, fig. 1 a-b.

Trifarina angulosa (WILLIAMSON 1858)

Plate 2, Figs. 5-6

1950a *Angulogerina angulosa* Van Voorthuysen p. 38, pl. 1, fig. 13.

1971 *Trifarina angulosa* Knudsen, p. 241, pl. 18, figs. 8-9.

1989 *Trifarina angulosa* King, p. 482, pl. 9.9, fig. 1.

1994 *Trifarina angulosa* Jones. p.86, pl. 74. figs. 15-16.

Stratigraphic Range: Middle Miocene - Recent (RF1)

                              Early Pliocene - Recent (RF3)

Trifarina bradyi CUSHMAN 1923

1989 *Trifarina bradyi* King, p. 9.9, fig. 2.

1994 *Trifarina bradyi* Jones, p. 78-79, pl. 67, figs. 1-3.

Stratigraphic Range: Miocene - Recent (RF1)

                              Late Oligocene - Late Pliocene (RF3)

Depth Range: 12 - 1360 fm (RF1)

Trifarina fluens (TODD 1947)

1953 *Angulogerina fluens* Loeblich & Tappan, p. 112, pl. 20, figs. 10-12.

1964 *Angulogerina fluens* Feyling-Hanssen, p. 318, pl. 16, figs. 4-5.

1971 *Trifarina fluens* Knudsen, p. 242, pl. 7, figs. 12-15; pl. 18, figs. 8-9.

1989 *Trifarina fluens* King, p. 482, pl. 9.9, fig. 3.

Stratigraphic Range: Pleistocene (living in Arctic areas) (RF3)

Trifarina gracilis (REUSS 1863)

1980 *Trifarina gracilis* Doppert, pl. 21, figs. 2 a-b.

Triloculina tricarinata D'ORBIGNY 1826

1964 *Triloculina tricarinata* Feyling-Hanssen, p. 258, pl. 6, figs. 7-8.

1985 *Triloculina frigida* Mackensen, p. 28, pl. 3, figs. 10-11.

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1992 *Triloculina tricarinata* Struck, p. 17, pl. 1, fig. 8.

Stratigraphic Range: Miocene - Recent (RF1)

Depth Range: 6 - 2350 fm (RF1)

Triloculina trihedra LOEBLICH & TAPPAN 1953

1953 *Triloculina trihedra* Loeblich & Tappan, p. 45, pl. 4, fig. 10.

1964 *Triloculina trihedra* Feyling-Hanssen, p. 259-260, pl. 6, fig. 6.

1971 *Triloculina trihedra* Knudsen, p. 196, pl. 2, fig. 7; pl. 15, fig. 8

1992 *Triloculina trihedra* Wollenburg, p. 42, pl.11. fig 4.

Turrilina alsatica ANDREAE 1884
Plate 2, Fig. 1,;Plate 3, Fig. 16

1986 *Turrilina alsatica* van Morkhoven *et al* , p. 306.

1989 *Turrilina alsatica* King, p. 482, pl. 9.8, fig 21.

1994 *Turrilina alsatica* Gradstein *et al* ., pl. 15, figs. 8-11.

Stratigraphic Range: Late Eocene?, Early Oligocene - Early Miocene (RF3)

Turrilina brevispira TEN DAM 1944

1986 *Turrilina brevispira* van Morkhoven *et al* , p. 305-308, pl. 100.

1989 *Turrilina brevispira* King, p. 482, pl. 9.8, fig. 22.

Stratigraphic Range: Early Eocene (RF3)

Uvigerina peregrina CUSHMAN 1923

1971 *Uvigerina peregrina* Knudsen, p. 240-241, pl. 7, figs. 9-11.

1989 *Uvigerina peregrina* King, p. 484.

Stratigraphic Range: Pleistocene - Recent (RF3)

Uvigerina pygmea D'ORBIGNY 1826

1980 *Uvigerina pygmea* Doppert, pl. 14, figs. 3 a-b.

Stratigraphic Range: Late Miocene (RF2)

Uvigerina tenuispustulata VAN VOORTHUYSEN 1950

1950b *Uvigerina tenuispustulata* Van Voorthuysen p. 60, pl. 2, fig. 13.

1980 *Uvigerina tenuispustulata* Doppert, pl. 16, figs. 4 a-b.

1989 *Uvigerina tenuispustulata* King, p. 484, pl. 9.9, fig. 12.

Stratigraphic Range: Early and Middle Miocene (RF3)

Uvigerina venusta saxonica VON DANIELS & SPIEGLER 1977

1989 *Uvigerina venusta saxonica* King, p. 484, pl. 9.9, fig. 14.

Stratigraphic Range: Late Miocene - Early Pliocene (RF3)

Vaginulina spirigera (REUSS 1855)
Plate 2, Fig. 14

1989 *Vaginulina spirigera* King, p. 466, pl. 9.4, fig. 13.

1994 *Vaginulina spirigera* Jones p. 79, pl. 67. figs. 13-14.

Bolboforms

Bolboforma badenensis SZCZECHURA 1982.

1991 *Bolboforma badenensis* Spiegler and von Daniels, p.133, pl. 2. figs. 1-4.

Bolboforma capsula SPIEGLER 1987

1991 *Bolboforma capsula* Spiegler and von Daniels, p.134, pl. 8. figs. 1-7.

Bolboforma compressi group SPIEGLER 1991

1991 *Bolboforma compressibadenensis and B. compressi spinosa* Spiegler and von Daniels, p.134, pl. 2. figs.5-6; pl. 6, fig. 3-4
The bolboforms were in general too badly preserved to allow further identification.

Bolboforma metzmacheri (CLODIUS 1922)

1991 *Bolboforma metzmacheri* Spiegler and von Daniels, p.137, pl. 4. figs. 1-4.

Bolboforma spinosa DANIELS & SPEIGLER 1974

1991 *Bolboforma spinosa* Spiegler and von Daniels, p.140, pl. 7. figs. 5-9.

Bolboforma subfragoris SPIEGLER 1991

1991 Spiegler and von Daniels, p.140, pl.11. figs. 3-6.

Bolboforma voeringensis (SPIEGLER 1987)

1991 *Bolboforma voeringensis* Spiegler and von Daniels, p.141, pl. 1. figs. 1-4; pl. 12, figs. 1-3.

Diatoms

Coscinodiscus spp
Plate 7, Fig. 12
Large biconvex pyritized diatoms, probably mostly *Coscinodiscus* sp 1 King (1991).
p. 20, pl. 1. figs. 1-2.

Diatom sp. 3 KING 1983
Plate 7, Fig. 9
1983 Diatom sp. 3 King, p. 20, pl. 1. fig. 4.

Diatom sp. 4 KING 1983
1983 Diatom sp. 4 King, p. 20, pl. 1. figs. 5-6.

Radiolarians and planktic foraminifers

Radiolaria spp.
Plate 7, Figs. 6-8
All radiolaria recorded are placed here. They range from well preserved spherical forms with spines, probably *Cenosphaera* spp. to
badly preserved forms.

Subbotina patagonica (TODD & KNIKER)
Plate 7, Figs. 10-11
1994 *Subbotina patagonica* Gradstein et al., pl. 19. fig. 12-15; pl. 20, figs. 11-16.
May also include some species of *S. frontosa* (Subbotina) and *S. eocenica* (Terquem)

PLATE 1

Fig. 1	*Elphidium bartletti*	Well 6406/11-1, 1040m	x92
Fig. 2	*Elphidium ustulatum*	Well 6406/11-1, 720	x110
Fig. 3	*Elphidium clavatum* forma *clavata*	Well 6406/11-1, 720m	x85
Fig. 4	*Elphidium macellum*	Well 6406/11-1, 600m	x87
Fig. 6	*Ammonia beccarii*	Well 6407/9-3, 420m	x65
Fig. 7	*Bucella frigida*	Well 6407/9-3, 390m	x152
Fig. 8	*Cassidulina laevigata*	Well 6407/9-3, 410m	x80
Fig. 9	*Cassidulina tertis*	Well 6406/11-1, 680m	x92
Fig. 10	*Cibicides grossus*: umbilical view	Well 6407/9-3, 470m	x60
Fig. 11	*Cibicides grossus*: spiral view	Well 6406/11-1, 620m	x61
Fig. 12	*Cibicides lobatulus*: umbilical view	Well 6406/11-1, 560m	x85
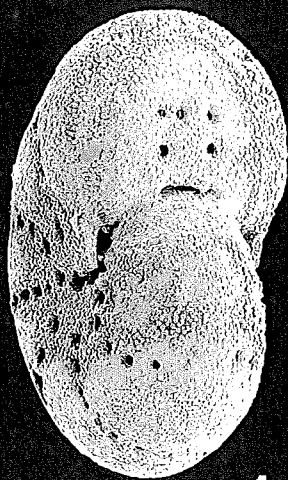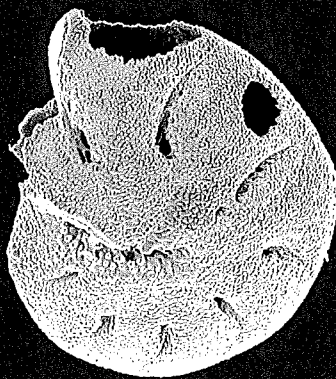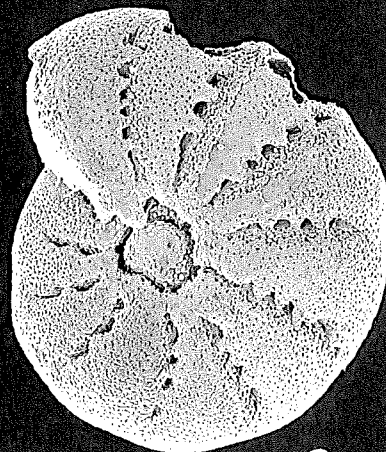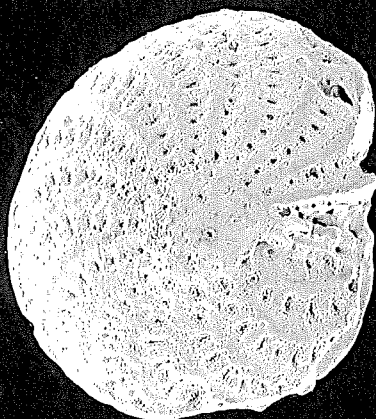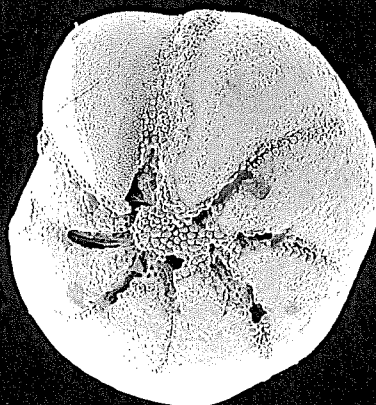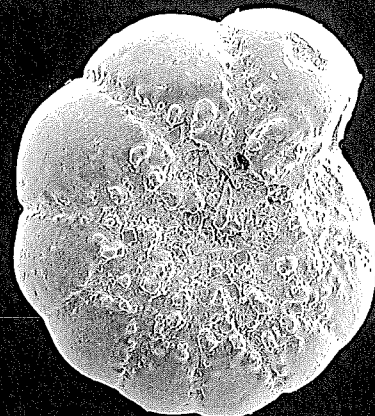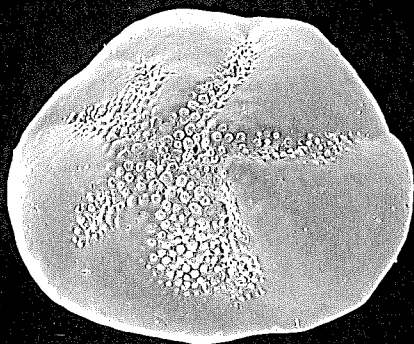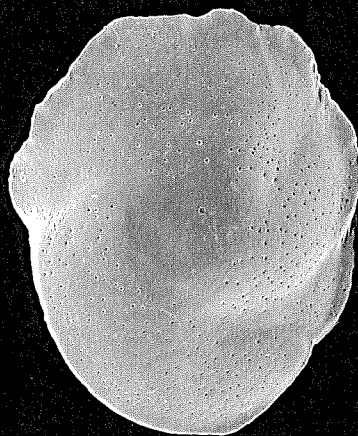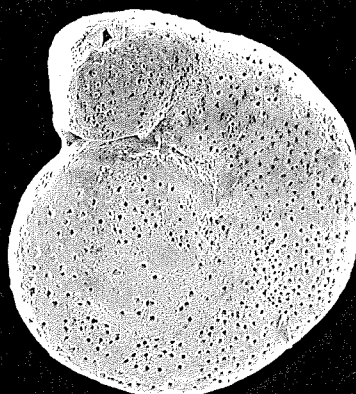
PLATE 2

Fig. 1	*Turrilina alsatica*	Well 6406/11-1, 1480m	x105
Fig. 2	*Bulimina gibba*	Well 6407/9-3, 670m	x82
Fig. 3	*Bulimina aculeata*	Well 6406/11-1, 900m	x112
Fig. 4	*Bulimina aculeata*	Well 6407/9-3, 420m	x100
Fig. 5	*Trifarina angulosa* (corroded)	Well 6406/11-1, 560m	x100
Fig. 6	*Trifarina angulosa*	Well 6407/9-3, 420m	x125
Fig. 7	*Bulimina marginata*	Well 6406/11-1, 1040m	x92
Fig. 8	*Bulimina marginata*	Well 6407/9-3, 420m	x80
Fig. 9	*Oolina borealis*	Well 6407/9-3, 390m	x165
Fig. 10	*Oolina melo*	Well 6406/11-1, 680m	x130
Fig. 11	*Miliolinella subrotunda*	Well 6406/11-1, 1080m	x42
Fig. 12	*Quinqueloculina seminulum*	Well 6406/11-1, 680	x34
Fig. 13	*Oolina williamsoni*	Well 6406/11-1, 840	x140
Fig. 14	*Vaginulina spirigera*	Well 6406/11-1, 1120m	x38
Fig. 15	*Lenticulina thalmanni*	Well 6406/11-1, 880m	x35
Fig. 16	*Sphaeroidina bulloides*	Well 6407/9-3, 780m	x87
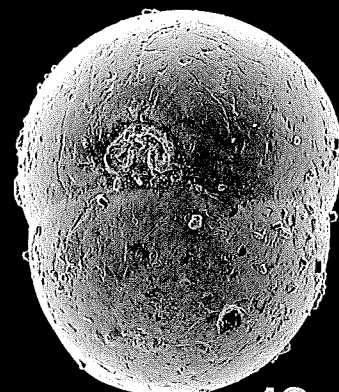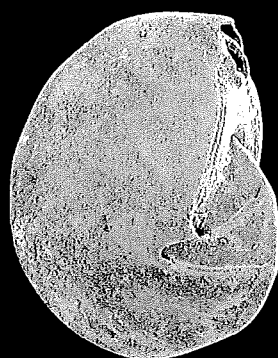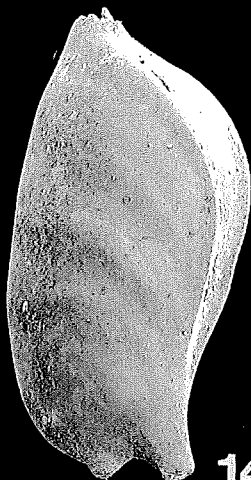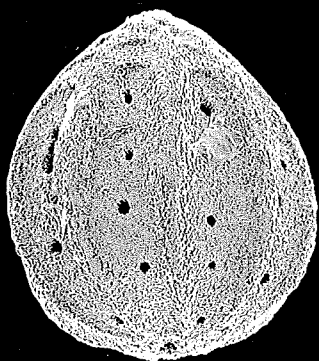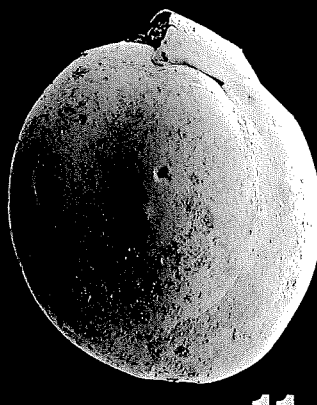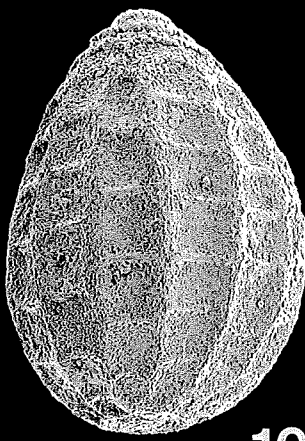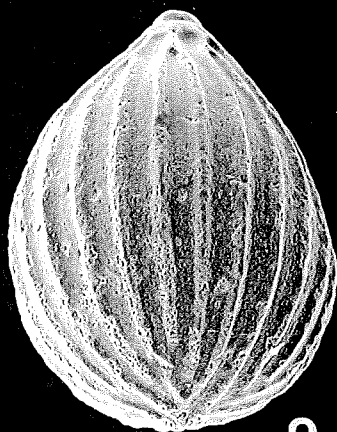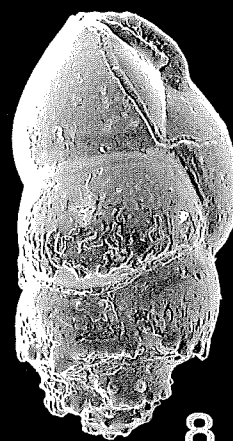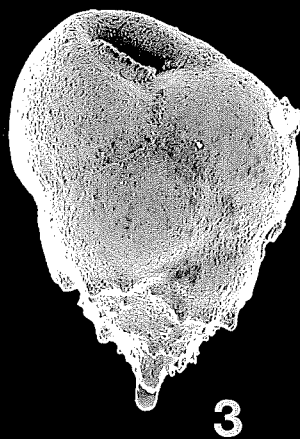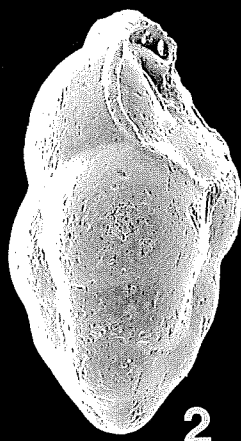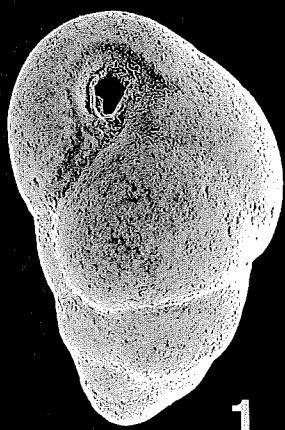
PLATE 3

Fig. 1	*Spiroplectammina spectabilis*	Well 6406/11-1, 1890m	x51
Fig. 2	*Spiroplectammina spectabilis*	Well 6407/7-2, 1970m	x75
Fig. 3	*Spiroplectammina spectabilis*	Well 6406/11-1, 2330m	x57
Fig. 4	*Bigenerina* sp.	Well 6407/7-2, 1950m	x75
Fig. 5	*Spiroplectammina navarroana*	Well 6406/11-1,2150m	x62
Fig. 6	*Karrerulina conversa*	Well 6407/7-2, 1760m	x58
Fig. 7	*Karrerulina conversa*	Well 6406/11-1,2350m	x51
Fig. 8	*Karreriella horrida*	Well 6407/7-2, 1760m	x115
Fig. 9	*Martinottiella communis*	Well 6406/8-1, 1680m	x31
Fig. 10	*Bathysiphon* sp.	Well 6406/8-1, 2760m	x39
Fig. 11	*Rhabdammina abyssorum*	Well 6406/11-1, 2350m	x80
Fig. 12	*Rzehakina minima*	Well 6406/11-1, 2260m	x92
Fig. 13	*Spirosigmoilinella compressa*	Well 6407/7-2, 1240m	x77
Fig. 14	*Rzehakina epigona*	Well 6406/8-1, 2710m	x100
Fig. 15	*Spirosigmoilinella compressa*	Well 6406/8-1, 1980m	x95
Fig. 16	*Turrilina alsatica*	Well 6406/11-1, 1480m	x233
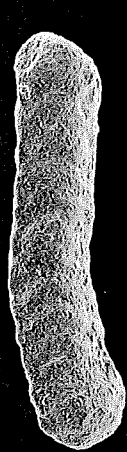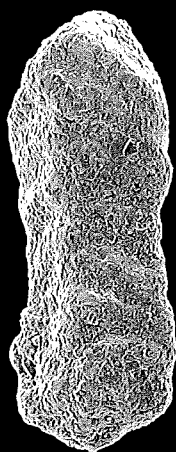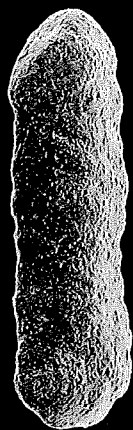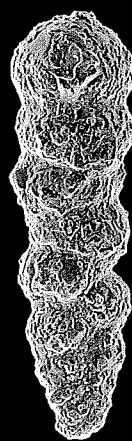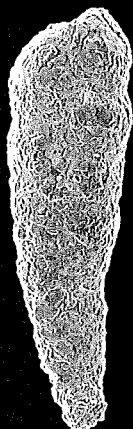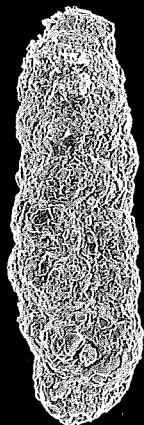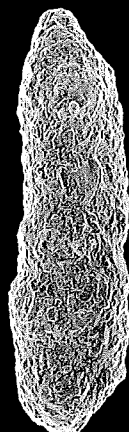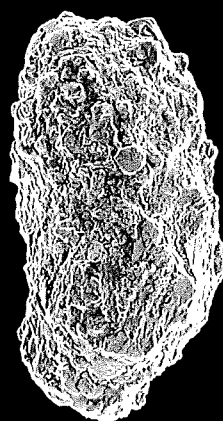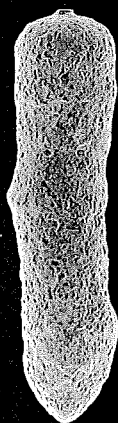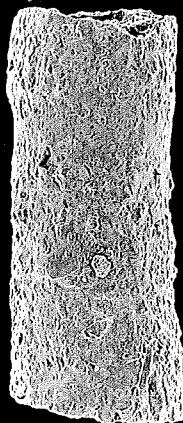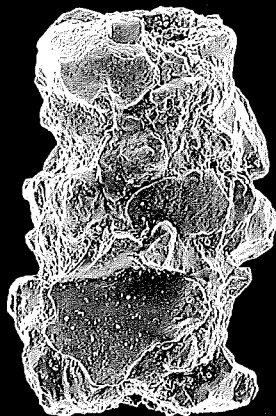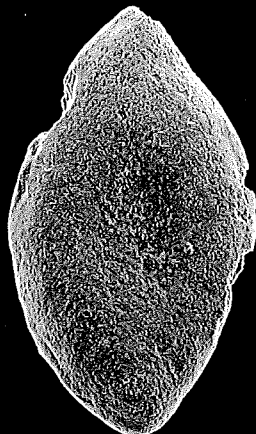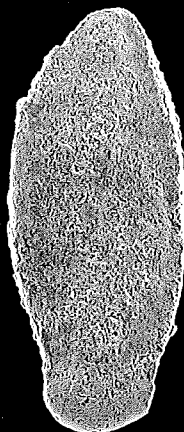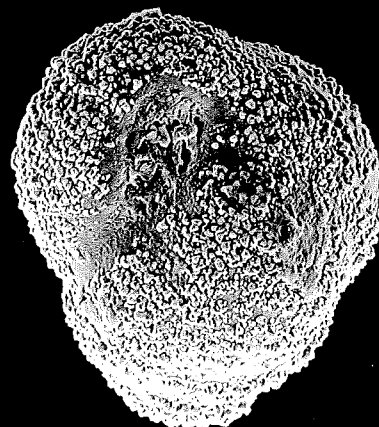
PLATE 4

Fig. 1	*Reticulophragmium amplectens*	Well 6407/7-2, 1760m	x64
Fig. 2	*Reticulophragmium amplectens*	Well 6407/7-2, 1870m	x80
Fig. 3	*Cyclammina placenta*	Well 6406/11-1, 1760m	x20
Fig. 4	*Reticulophragmium intermedia*	Well 6407/7-2, 1570m	x115
Fig. 5	*Haplophragmoides walteri*	Well 6406/8-1, 2710m	x150
Fig. 6	*Haplophragmoides* cf. *kirki*	Well 6407/9-3, 1300m	x147
Fig. 7	*Haplophragmoides stomatus*	Well 6407/7-2, 1760m	x110
Fig. 8	*Haplphragmoides porrectus*	Well 6407/7-2, 1710m	x162
Fig. 9	*Haplophragmoides kirki*	Well 6406/11-1, 2280m	x155
Fig. 10	*Haplophragmoides* sp. 2	Well 6407/7-2, 1670m	x105
Fig. 11	*Trochammina altiformis*	Well 6407/7-2, 1730m	x77
Fig. 12	*Recurvoides* ex gr. *turbinatus*	Well 6407/7-2, 1910m	x85
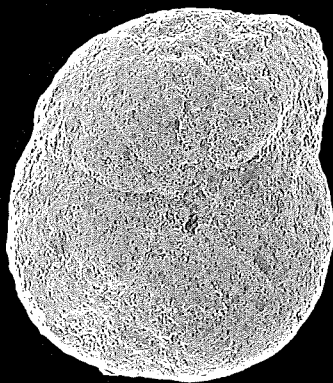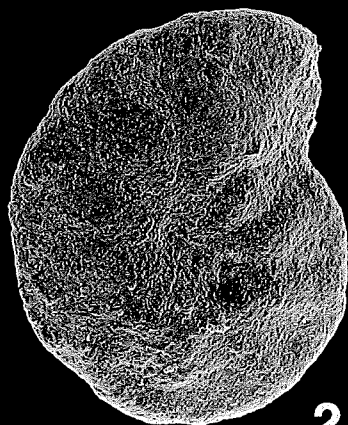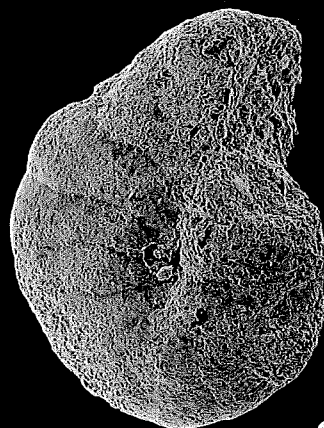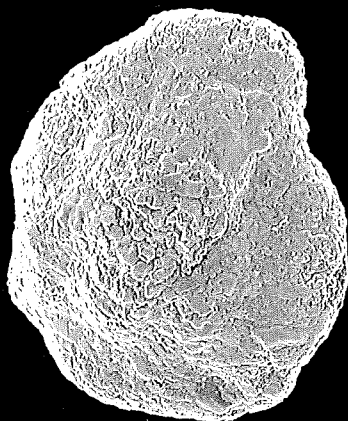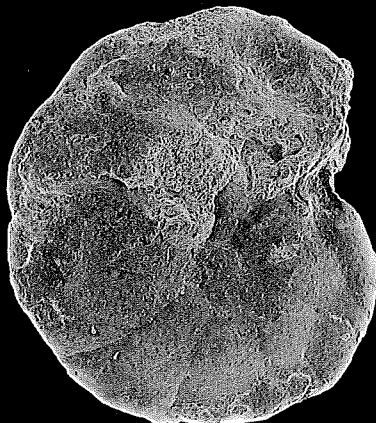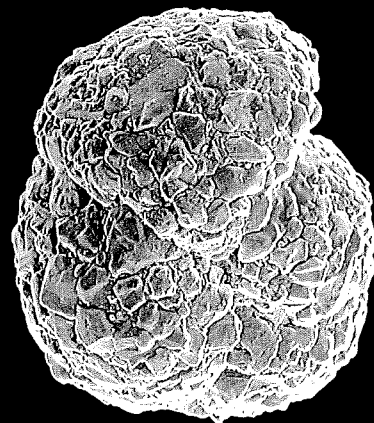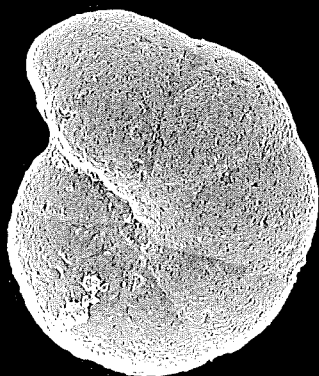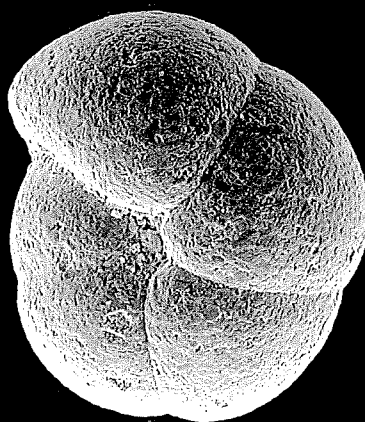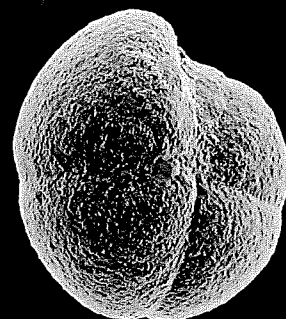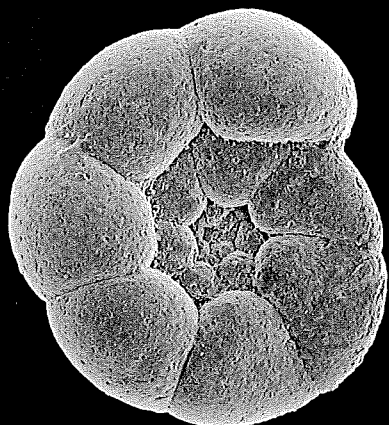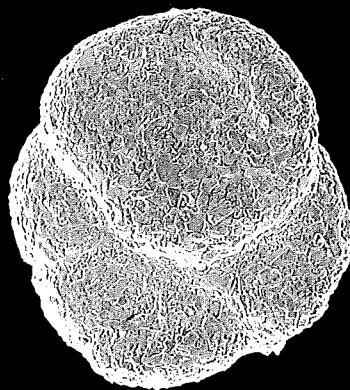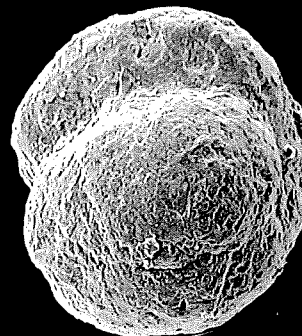
PLATE 5

Fig. 1	*Ammodiscus cretaceus*	Well 6407/9-3, 1950m	x65
Fig. 2	*Ammodiscus tenuissimus*	Well 6407/7-2 1710m	x200
Fig. 3	*Ammodiscus pennyi*	Well 6407/7-2, 1720m	x80
Fig. 4	*Glomospira charoides*	Well 6407/9-3, 960m	x130
Fig. 5	*Cystammina pauciloculata/C. sveni*	Well 6407/7-2, 1720m	x120
Fig. 6	*Glomospira glomerata*	Well 6406/8-1, 2080m	x35
Fig. 7	*Cystammina pauciloculata/C. sveni*	Well 6407/7-2, 1760m	x115
Fig. 8	*Cystammina pauciloculata/C. sveni*	Well 6407/7-2, 1760m	x100
Fig. 9	*Glomospira charoides*	Well 6407/9-3, 960m	x160
Fig. 10	*Cribrostomoides* sp. 1	Well 6407/7-2, 1670m	x192
Fig. 11	*Cribrostomoides* sp. 1	Well 6407/7-2, 1670m	x162
Fig. 12	*Ammomarginulina aubertae*	Well 6407/7-2, 1670m	x127
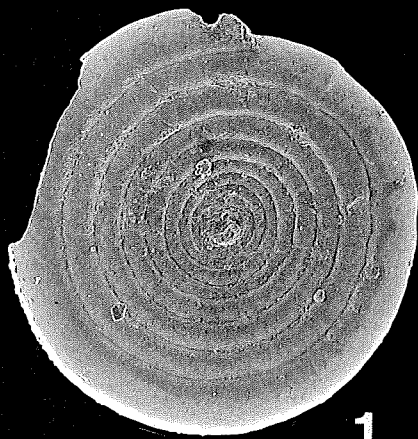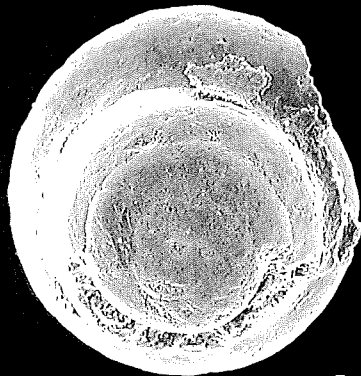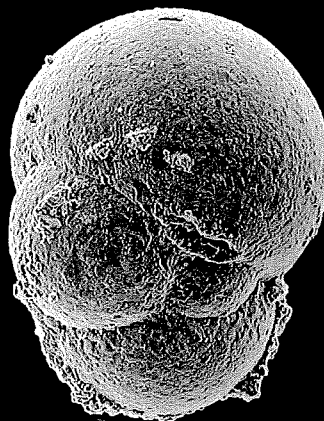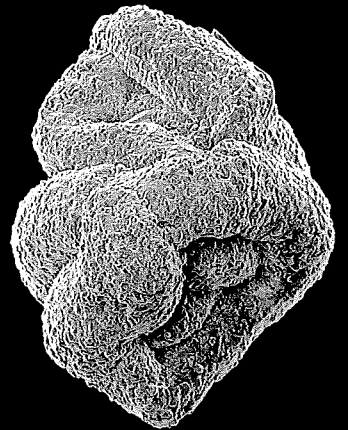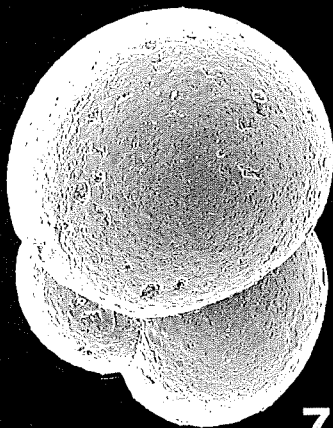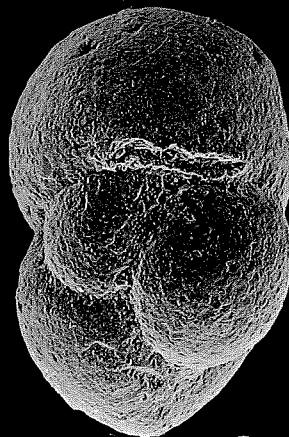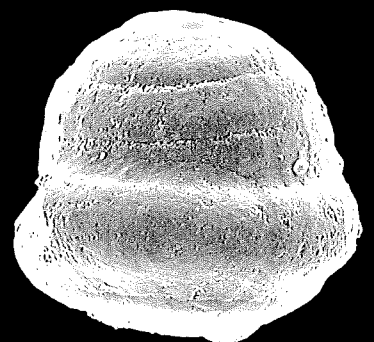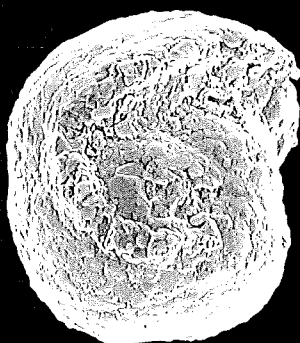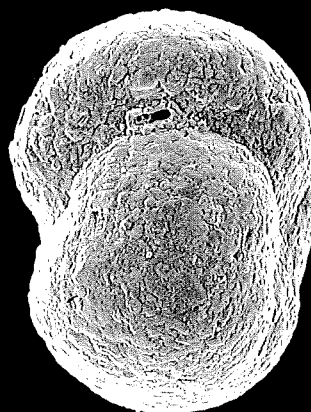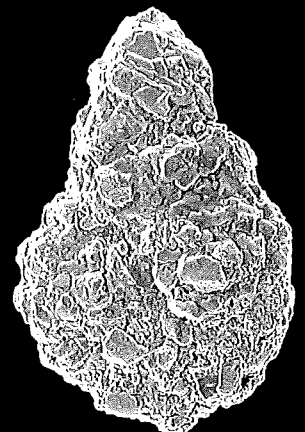
PLATE 6

Fig. 1	*Adercotryma agterbergi*	Well 6407/7-2, 1650m	x85
Fig. 2	*Recurvoides* sp.2	Well 6407/7-2, 1280m	x175
Fig. 3	*Recurvoides* sp. 3	Well 6407/7-2, 1930m	x60
Fig. 4	*Trochammina* sp. 5	Well 6407/7-2, 2480m	x175
Fig. 5	*Trochammina* sp. 5	Well 6407/7-2, 2480m	x155
Fig. 6	*Recurvoides* ex. gr. *gerochi*	Well 6407/7-2, 1980m	x110
Fig. 7	*Trochamminoides dubius*	Well 6407/9-3, 1280m	x95
Fig. 8	*Trochamminoides irregularis*	Well 6407/9-3, 1410m	x67
Fig. 9	*Conglophragmium coronatum*	Well 6407/7-2, 2740m	x36
Fig. 10	*Trochammina ruthven-murrayi*	Well 6407/9-3, 1440m	x62
Fig. 11	*Trohammina subvesicularis*	Well 6407/7-2, 1910m	x122
Fig. 12	*Trochammina ruthven-murrayi*	Well 6406/11-1, 2310m	x100
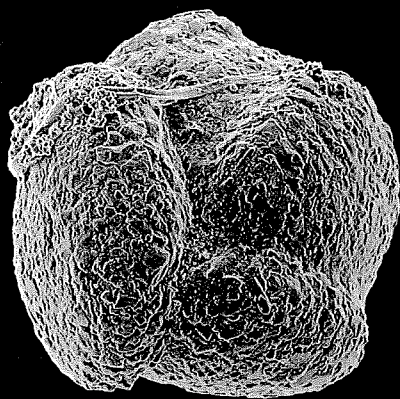
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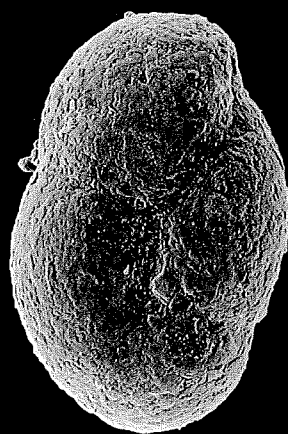
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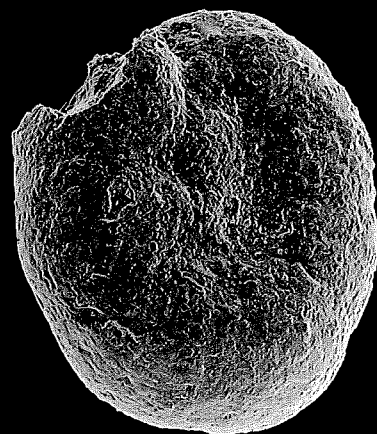
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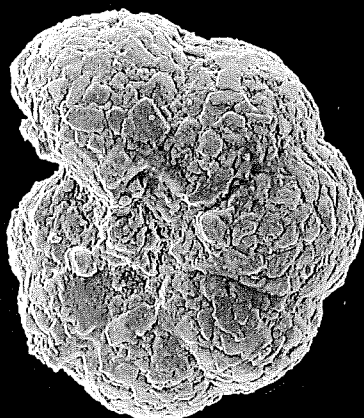
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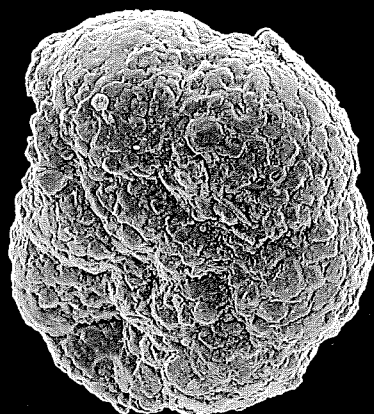
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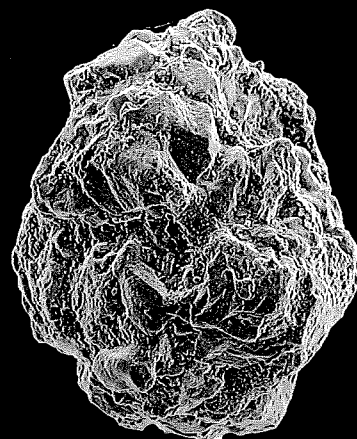
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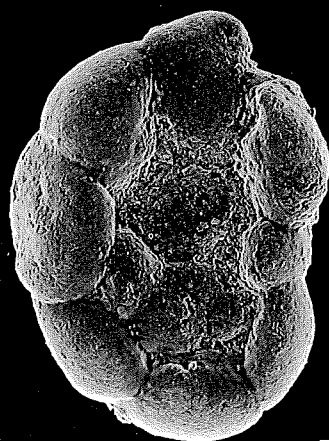
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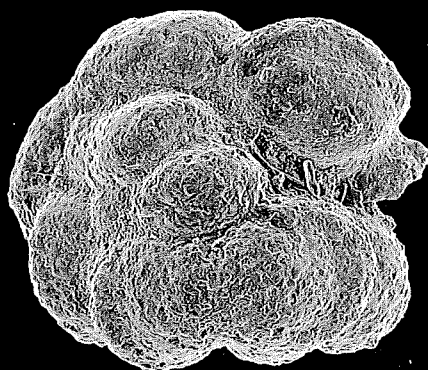
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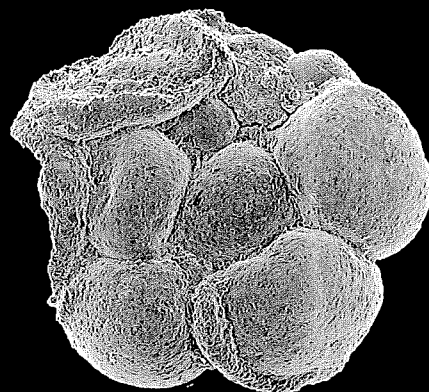
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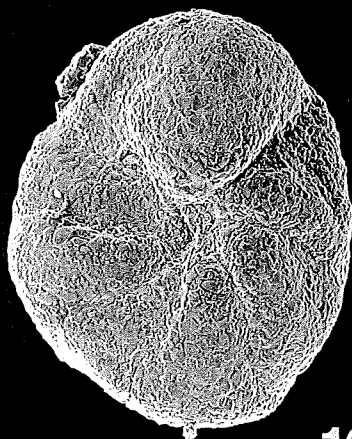
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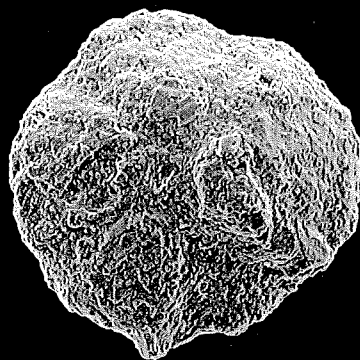
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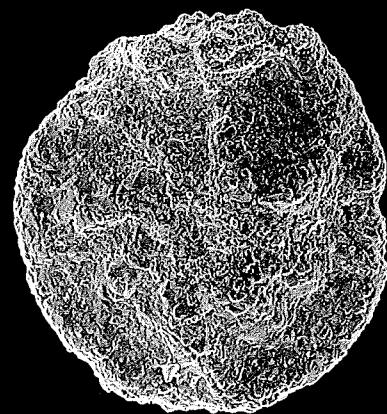
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PLATE 7

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Fig. 1	*Bolboforma spinosa*	Well 6406/11-1,1270m	x235
Fig. 2	*Bolboforma capsula*	Well 6406/11-1, 1240m	x250
Fig. 3	*Bolboforma subfragoris*	Well 6406/11-1, 1290m	x310
Fig. 4	*Bolboforma compressi* gp.	Well 6406/11-1, 1270m	x266
Fig. 5	*Bolboforma compressi* gp.	Well 6406/11-1, 1250m	x220
Fig. 6	radiolarian	Well 6406/8-1, 1600m	x250
Fig. 7	radiolarian	Well 6406/11-1, 1310m	x235
Fig. 8	radiolarian	Well 6407/7-2, 1310m	x200
Fig. 9	Diatom sp. 3	Well 6406/8-1, 2020m	x145
Fig. 10	*Subbotina patagonica*	Well 6407/9-3, 1330m	x142
Fig. 11	*Subbotina patagonica*	Well 6407/9-3, 1330m	x110
Fig. 12	*Coscinodiscus* sp.	Well 6406/8-1, 2640m	x110
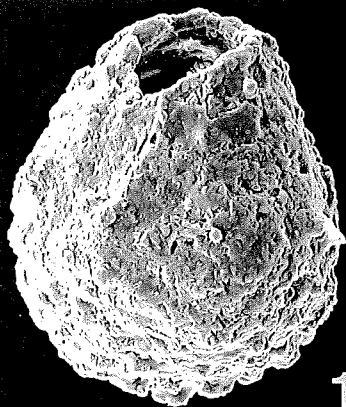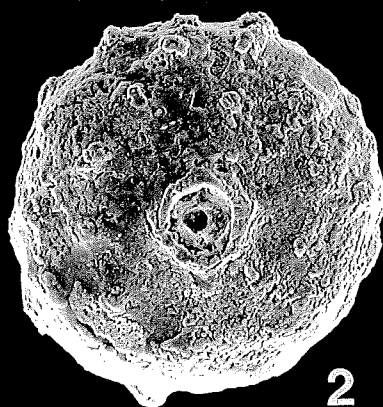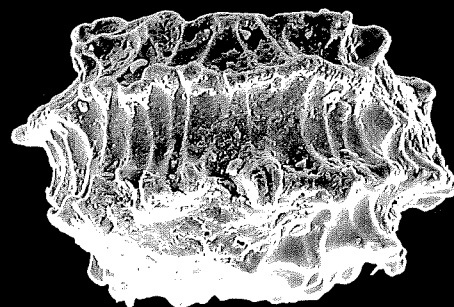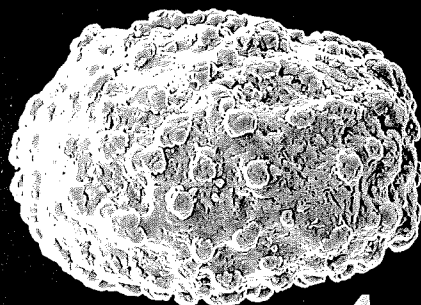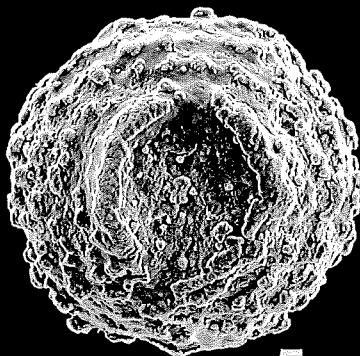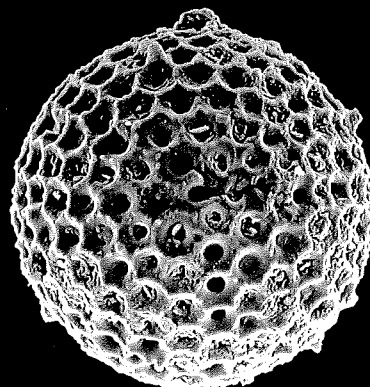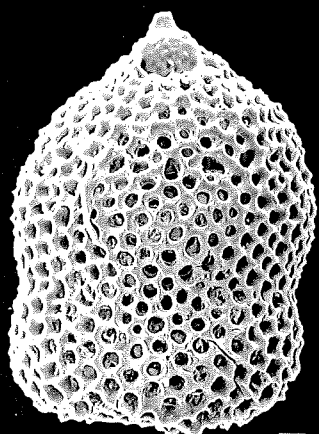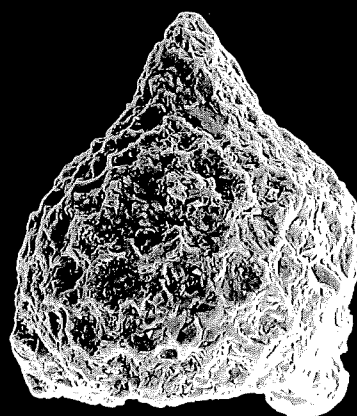
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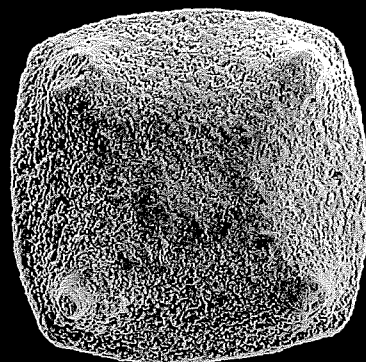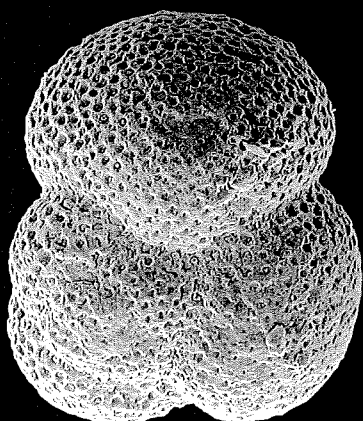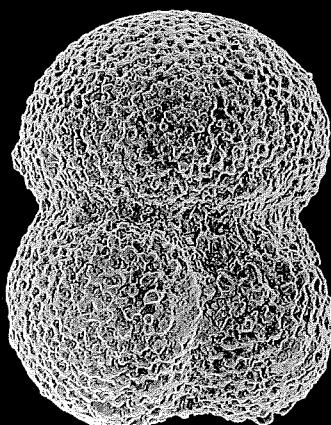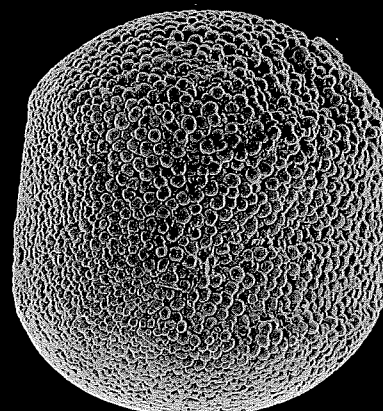Aagaard, K., Swift., J.H., and Carnock, E.C. (1985). Thermohaline circulation in the Arctic Mediterranean seas. *Journal Geophysical Rerearch*, 90: 4833-4846.

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Acknowledgements

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