

## Palaeogene benthic foraminiferal biostratigraphy of the Halten Terrace area, Norway

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### ABSTRACT

Benthic foraminiferal assemblages were studied from four wells on the Norwegian Shelf near the Halten Terrace. A biostratigraphic scheme based mainly on benthic foraminifers but also including planktic foraminifers, diatoms and radiolarians is proposed for the Palaeogene interval which enables the correlation of the four wells. The scheme has been correlated to other biostratigraphies from the same or adjacent areas such as the North Sea and Barents Sea.

The late Palaeocene is characterised by abundant and diverse agglutinated foraminiferal assemblages. The Palaeocene/Eocene boundary marks the opening of the Norwegian-Greenland Sea and a change to more impoverished assemblages. Above this there is a brief interval where planktic foraminifers are recorded, before a return to wholly agglutinated, organically cemented assemblages. Biosiliceous sedimentation and deteriorating oxygenation started in the Eocene, and continued throughout Oligocene and early Miocene.

### INTRODUCTION

Several attempts have been made to produce a foraminiferal zonal scheme for the area of the Norwegian Sea (Hulsbos *et al.*, 1989; Osterman & Qvale, 1989; Kaminski *et al.*, 1990; Poole & Vorren, 1993; Gradstein & Bäckström, 1996; Osterman & Spiegler, 1996; Nagy *et al.*, 1997). The main problem encountered when trying to correlate schemes from the Norwegian Sea to other areas such as the North Sea, Labrador Sea and Northern Atlantic 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, including 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.

### STUDY AREA

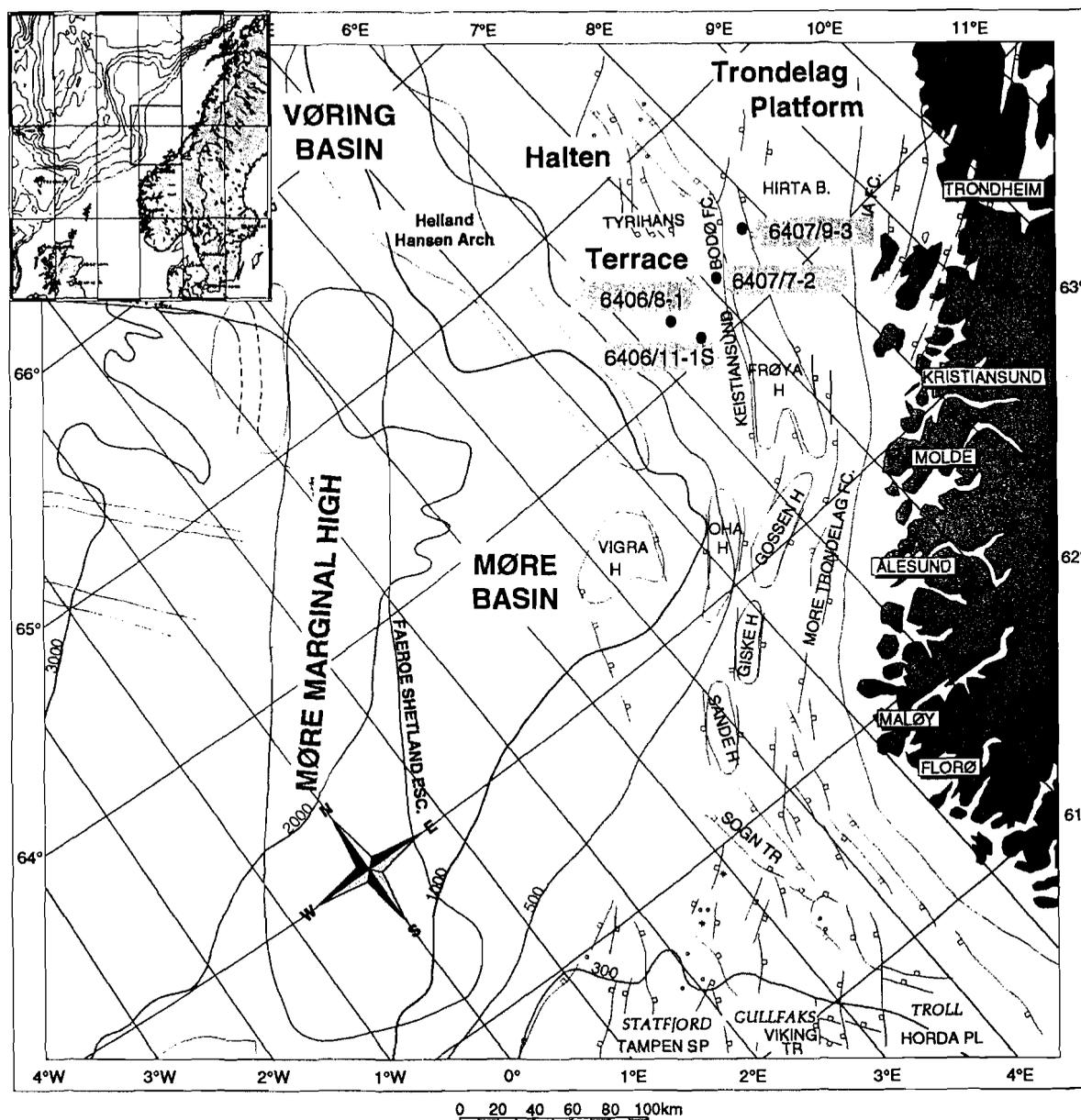
The locations of the four wells: 6406/8-1, 6406/11-s, 6407/7-2, 6407/9-3 on the Norwegian Shelf are shown in Figure 1. Present day water depths of the wells range from 279 m to 348 m.

The present day Norwegian Shelf margin is a Cenozoic feature but much of its post-depositional history was determined by its pre-opening structural

history (Myhre *et al.*, 1992; Thiede & Myhre 1996b). 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 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 (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 Palaeocene (Myhre *et al.*, 1992).

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 200 m and is narrow with widths of 60-80 km. Further to the north the shelf expands to widths of up to 180-200 km and is also



**Figure 1.** Location of the studied wells on the Halten Terrace. ESC – escarpment; FZ – fracture zone; FC – fault complex; B – basin complex; H – high; PL – platform; TR – trough; SP – spur; depth contours in metres. Modified from Hammar & Hjelle (1984).

deeper than its southern counterpart, generally having depths greater than 200 m. Large depressions and channels of up to 540 m are also found (Holte Dahl, 1993). The nearby Frøya Bank and Halten Bank are extensive and have minimum depths of 100-150 m (Holte Dahl, 1993). The Møre-Trondelag and Kristiansund-Bodo fault complexes plus a number of major structural highs also occur in this area (Hamer & Hjelle, 1984).

Prior to the opening of the Norwegian Sea, the continental part of the present margin may have been either a shallow epicontinental (Myhre *et al.*, 1992), or mid- to upper bathyal (Gradstein, pers. comm., 1998) sea which extended into the North Sea and Barents Sea. During the early Tertiary the opening of the Norwegian-Greenland Sea occurred

around the time of the Palaeocene/Eocene boundary at about 57.5 Ma (Eldholm *et al.*, 1989; Talwani & Eldholm, 1977). Between Anomalies 25/24B and 13 Greenland moved in a NW direction relative to Eurasia. 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).

During the Palaeogene, deposition along the rifted margin was dominated by rift induced uplift which gave rise to the erosion of highs and redepo-

sition on the outer Møre and Vøring Basins. Continued subsidence but waning siliclastic sedimentation 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 & Eldholm, 1996).

The Fram Strait provides the sole 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 2 km) to allow deeper waters from the Arctic into the Norwegian Sea (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 Faeroe-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 & Tucholke, 1983). During the Palaeocene 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 & Myhre, 1996a). Cool to temperate waters probably first appeared during the late Oligocene to early Miocene (Thiede & Myhre 1996a).

Deep water and abyssal overflow across the Greenland-Scotland Ridge probably did not take place until the mid- to late Miocene, about 13-11 Ma. and occurred first across the Iceland-Scotland segment of the ridge (Bohrmann *et al.*, 1990).

#### METHODS AND MATERIALS

The analyses were carried out on cuttings samples. In using cuttings samples there is the problem-ugh '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 see King (1983). Therefore, the most reliable method for constructing a biostratigraphic time scale or zonation scheme is by recording the extinctions (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 foraminifera can be recognised by a variety of means,

e.g., different modes and degrees of preservation of the predominant fauna, and obviously out of place forms such as Pliocene planktic foraminifera and calcareous benthic foraminifera in the predominantly agglutinated sections of the Palaeocene and Eocene. Samples from the wells were studied approximately every 10-20 m. Sampling usually began at about 100-300 m below the sea floor. Above this, sample material was not collected but returned straight to the sea bed.

Since the amount of sample received for each well varied widely (e.g., from 5-50 g) 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 20 g or greater was taken for micropalaeontological purposes. In the case of Well 6406/8-1 much less material was available and therefore the samples were often 10 g or less.

The samples were first soaked in distilled water for 24 hrs, freeze-dried and then weighed to obtain the total dry weight of sediment. Due to the high clay content, which proved difficult to get rid of especially in the lower samples, a number of further preparation methods were tested to disaggregate 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<sub>2</sub>O<sub>2</sub>, to 4 parts water) for a maximum of 24 hrs, wet sieve through a 63 µm sieve and then dry at 40°C, although even with this method some clay aggregates remained. However, with even harsher methods of preparation, there was the risk that some foraminifera 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 63-125 µm, 125-250 µm, 250-500 µm, 500-1000 µm and >1000 µm and weighed. For the micropalaeontological investigations the fractions 125-250 µm, 250-500 µm and 500-1000 µm were used. Using a binocular microscope foraminifera were picked from each depth and mounted on faunal slides. Wherever possible at least 300 foraminifera were picked. Other microfossils such as ostracods, diatoms, radiolarians, bolboforma, and fish teeth were also picked and/or counted.

#### BIOSTRATIGRAPHY

The assemblages of the four wells in this study were defined by using first downhole occurrences and acme occurrences of benthic foraminifera - both agglutinated and calcareous. Within each well the extinctions or last occurrence (LO) and last common occurrence (LCO) of microfossils were noted.

Figure 2 shows the assemblages defined for each of the wells. Using the observations from the four wells a composite biostratigraphy was created.

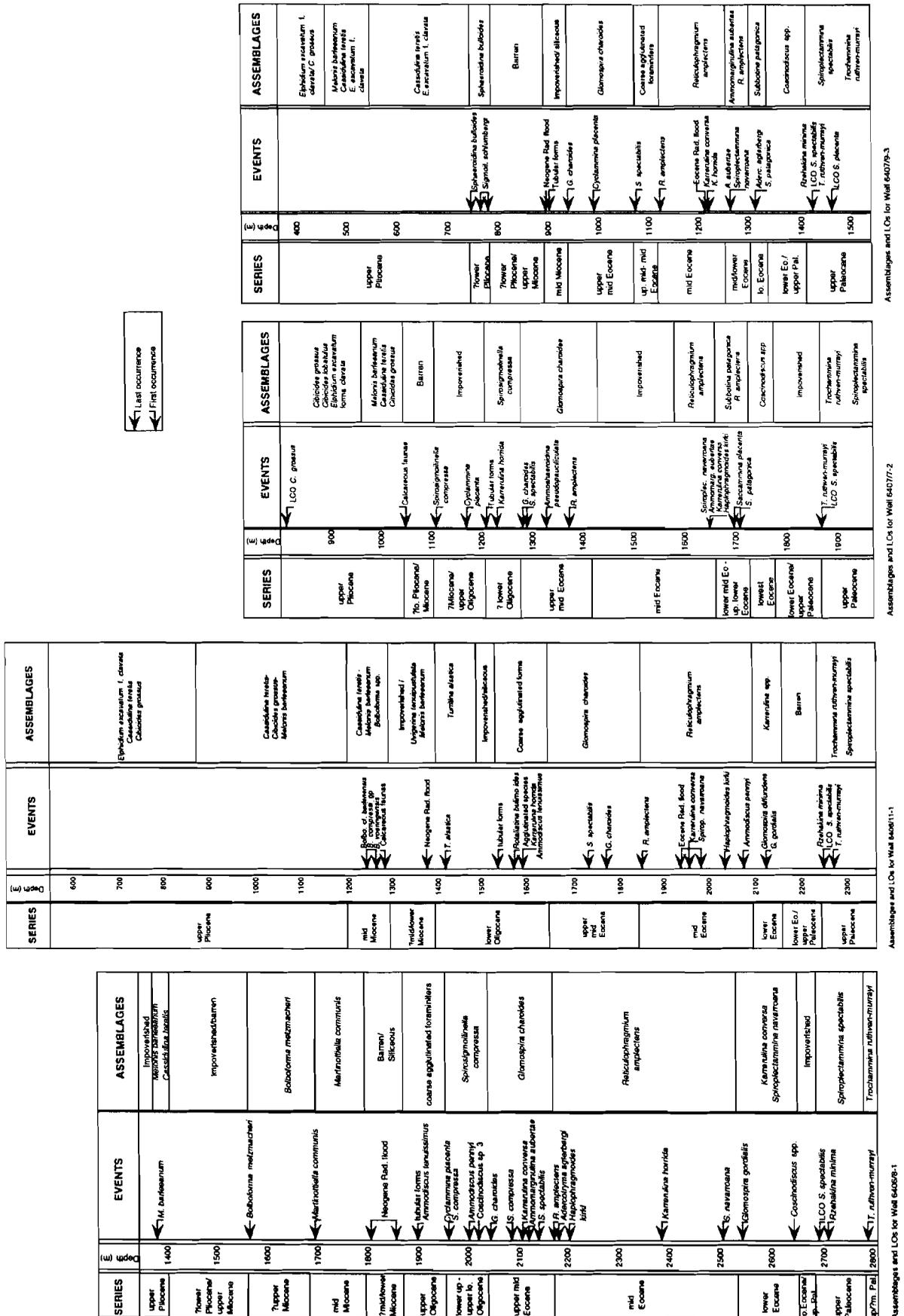


Figure 2. Microfossil assemblages and first & last occurrences in each of the Halten Terrace wells studied.

Although the emphasis of this work is upon benthic foraminifera, in some intervals these are either not present or are not age diagnostic. Thus, in order to present a stratigraphic scheme that is as complete as possible and contains easily identifiable and, where possible, abundant markers, other groups, namely planktic foraminifera, diatoms, bolboforma, and radiolarians, were also incorporated into the biostratigraphy. Such an integrated approach is useful when dealing with cuttings samples which may often be small in quantity and variable in quality and has been successfully applied by Gradstein *et al.* (1994) and Gradstein & Bäckström (1996) to the Halten Bank and North Sea areas. Dating the samples was further complicated by the general lack of index planktic foraminifera and of isotopic or magnetostratigraphic data.

#### PROPOSED BIOSTRATIGRAPHIC SCHEME FOR THE HALTEN TERRACE AREA

Figure 3 shows the assemblages of the composite biostratigraphy and their characteristic microfossils. Lower Palaeocene and Upper Eocene sediments were not observed in the wells studied. This is common in the Norwegian Sea and especially so on Halten Bank (Dalland *et al.*, 1988; Kaminski *et al.*, 1990; Myhre *et al.*, 1992; Gradstein *et al.*, 1994; Gradstein & Bäckström, 1996; Stuevold & Eldholm, 1996). The Lower Palaeocene hiatus has been ascribed to Late Cretaceous/Palaeocene syn-rift uplift (Stuevold & Eldholm, 1996) and the upper Eocene hiatus to intensified deep sea circulation leading to erosion (Thiede *et al.*, 1989; Tucholke & Mountain, 1986). The top of the mid-Eocene here is marked by a loss of foraminifera and a large increase in siliceous microfossils. The absence of the early Palaeocene and late Eocene index fossils (as defined by Gradstein *et al.*, (1994) and Gradstein & Bäckström (1996)) further points to the absence of these sediments in the wells studied although bad preservation and very low numbers of foraminifera recovered from the Middle Eocene onwards make exact identification and division of zones somewhat difficult. In general, tubular forms such as *Rhabdammina* spp., *Rhizammina* spp. and *Bathysiphon* spp. dominate all the assemblages. Figure 4 shows the correlation of the four wells with one another.

##### 1. *Trochammina ruthvenmurrayi* - *Spiroplectammina spectabilis* Assemblage

Age: late Palaeocene

Diverse and abundant assemblage which is exclusively composed of agglutinated foraminifera. The foraminifera 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 foraminifera are typical 'flysch-type' faunas. *Rzehakina minima*, *Subreophax* spp. and *Trochamminoides* spp. are generally confined to the assemblage.

##### 2. Impoverished Assemblage

Age: late Palaeocene/early Eocene

Low abundance and low diversity assemblage with foraminifera 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 assigned to *Coscinodiscus* spp. These are generally pyritized. The foraminifera that are seen are again those from Assemblage 1.

##### 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 agglutinated benthic diversity and abundance. Many of the foraminifera 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 foraminifera 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 amplexens* also appears in the assemblage but has its acme in the overlying one.

##### 6. *Reticulophragmium amplexens* Assemblage

Age: mid-Eocene

Diversity tends to decrease within this assemblage as *R. amplexens* is very dominant, often more so than the tubular forms. Other typical foraminifera 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 foraminifera 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. *Turritina alsatica* - *Spirosigmoilinella compressa* Assemblage

Age: early Oligocene/?late Oligocene

A low abundance and diversity assemblage.

Assemblages		Characteristic microfossils	
E Mio.	Unzoned	Occasional calcareous benthics radiolarians, diatoms	9
L. Olig.	Interval		
E.Olig.	<i>Turrilina alsatica</i> <i>Spirosigmoilinella compressa</i>	<i>Turrilina alsatica</i> <i>Spirosigmoilinella compressa</i> Coarse agglutinated foraminifers	8
L.Eo.		<i>Glomospira charoides</i> <i>Cyclammina placenta</i>	7
M.Eo.	<i>Glomospira charoides</i> <i>Reticulophragmium amplexens</i>	<i>Reticulophragmium amplexens</i> <i>Crirostomoides</i> spp. <i>Recurvoides</i> spp. <i>Haplophragmoides</i> spp.	6
E.Eo.	<i>Karrieriella</i> spp. <i>Spiroplectammina navarroana</i> <i>Subbotina patagonica</i> <i>Coscinodiscus</i> spp.	<i>Karrieriella conversa</i> <i>Karrieriella horrida</i> <i>Ammomarginulina aubertae</i> <i>Spiroplectammina navarroana</i> <i>Reticulophragmium amplexens</i> <i>Haplophragmoides kirki</i> <i>Haplophragmoides porrectus</i> <i>Recurvoides</i> spp.	5
L.Pal.	Impoverished <i>Trochammina ruthvenmurrayi</i> <i>Spiroplectammina spectabilis</i>	<i>Subbotina patagonica</i> <i>Karrieriella conversa</i> <i>Karrieriella horrida</i> <i>Ammomarginulina aubertae</i> <i>Spiroplectammina navarroana</i> <i>Reticulophragmium intermedia</i>	4
E. Pal.		<i>Coscinodiscus</i> spp. foraminifers from Assemblage 1	3
		Scattered appearance of foraminifers from Assemblage 1	2
		<i>Trochammina ruthvenmurrayi</i> <i>Spiroplectammina spectabilis</i> <i>Saccammina placenta</i> <i>Trochamminoides</i> spp. <i>Ammodiscus</i> spp. <i>Glomospira</i> spp. <i>Haplophragmoides walteri</i> <i>Bathysiphon</i> spp. <i>Rhabdammina</i> spp.	1

Figure 3. Microfossil assemblages and characteristic taxa for the proposed Halten Terrace biostratigraphy

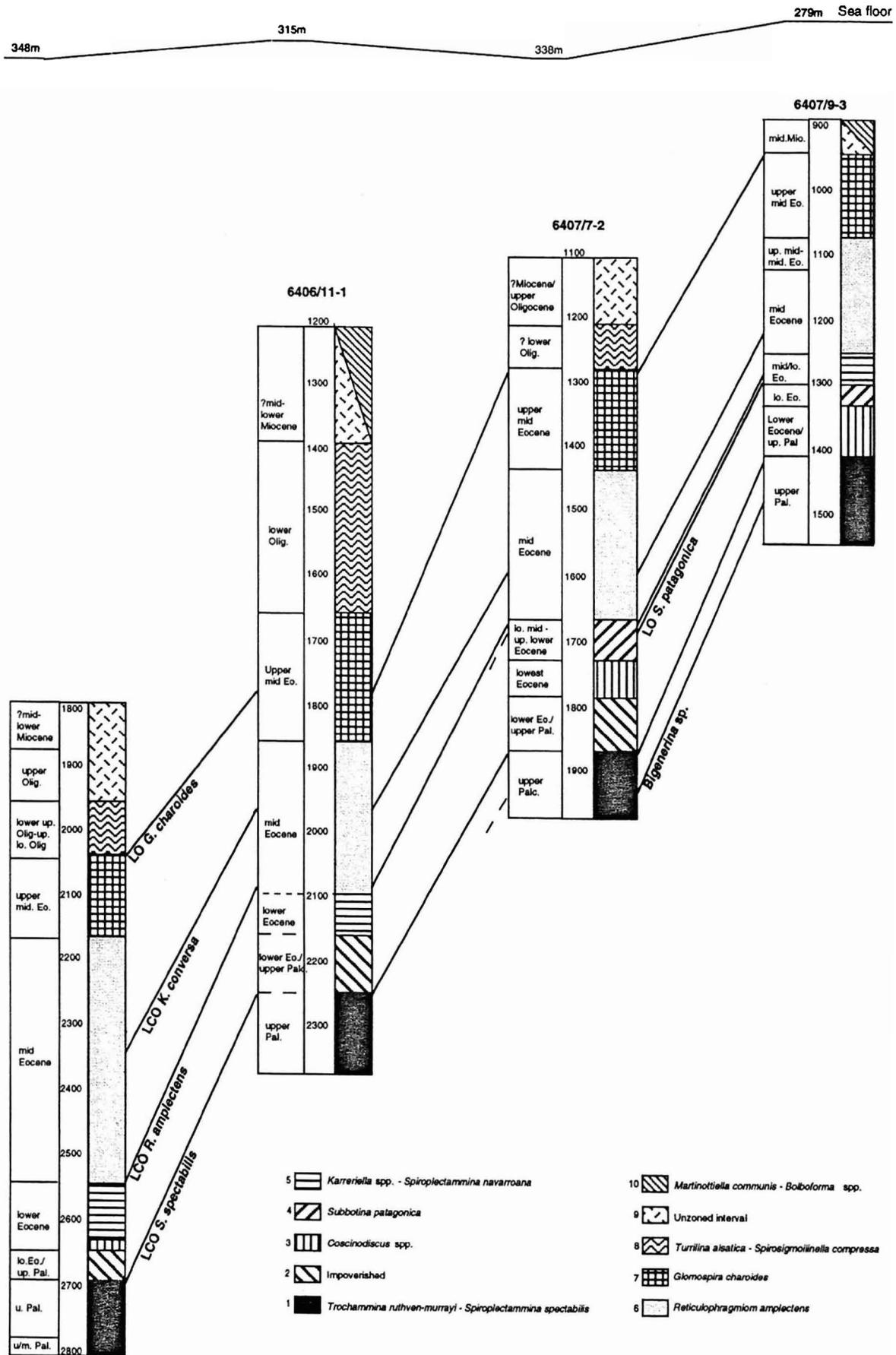


Figure 4. Correlation of the Halten Terrace wells, based on microfossil last occurrences.

Apart from the two nominate taxa *Rotaliatina bulimoides* is also occasionally recorded. Coarse agglutinated foraminifers and some poorly 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 sections. A few badly preserved calcareous foraminifers may be observed. Siliceous microfossils, especially radiolarians, are dominant.

### COMPARISON WITH OTHER BIOSTRATIGRAPHIC SCHEMES

The biostratigraphy here has been correlated with other schemes from the same or adjacent areas. The main schemes published to date are discussed below. Figure 5 shows the approximate correlation between the biostratigraphy from this study and those most relevant to it.

Gradstein *et al.* (1992), Gradstein *et al.* (1994) and Gradstein & Bäckström (1996) have produced composite biostratigraphies for the northern North Sea area and Halten Bank incorporating both foraminifers and dinoflagellates. Their material also consisted of cuttings. To produce the biostratigraphy they used two quantitative biostratigraphy software programs: 1. Ranking and scaling which considers the stratigraphic order of all (pairs of) events in wells simultaneously and calculates the most likely sequence of events (Gradstein & Bäckström, 1996); and 2. a probabilistic graphic zonation using the program STRATCOR. For fuller details on how these programs work see references cited above.

The LO sequences observed in each well in this study were correlated with this optimum sequence. In general, the plots show a good correlation apart from the LO of *Saccamina placenta* and the LO of *Spiroplectammina spectabilis* which plot consistently higher in the Halten Terrace wells. In both cases in the wells studied here, above the Palaeocene 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 (e.g., the LOs of *Cyclammina rotundidorsata* and *Adercotryma agterbergi* in wells 6407/7-2, 640678-1 and 6407/9-3) may be due to only partial ranges being observed in the Halten Terrace wells and to caving. Gradstein & Bäckström (1996) also 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 their final optimum sequence.

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.

The work of Nagy *et al.* (1997), based on wells to the north of this area, has results similar to those in this study. They also report a low diversity section around the Palaeocene/Eocene boundary and their Early 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.

ODP Site 643 on the slope of the Vøring Plateau (present day water depth 2768 m) was much deeper than the sites studied here. Kaminski *et al.* (1990) reported that the site was at mid-bathyal depths in the early Eocene, lower bathyal depths in the mid-Eocene and by the Early Oligocene was abyssal. The sites on the Halten Terrace, however, underwent a shallowing through time. One of the main differences to be noted is in the *Reticulophragmium amplexens* range. At ODP Site 643 it ranges into the upper Oligocene while in the Halten Terrace area its LO is within the upper mid-Eocene. If *R. amplexens* is a 'deep' water species then this may be the explanation for its earlier disappearance on the Halten Terrace. Kaminski *et al.* (1990) also stated that their *Glomospira* spp. Assemblage represents the first appearance of *Glomospira* into the Norwegian Sea. *Karrerulina conversa* and *Trochamminoides* sp. also all had first occurrences in this assemblage during the early middle Eocene. However in the Halten Terrace wells all these forms are also present in the Palaeocene and the *Glomospira* assemblage would seem to occur somewhat later, in the late mid-Eocene. Kaminski *et al.* (1990) also found the ranges of *Spirosigmoilinella compressa* and *Reticulophragmium amplexens* overlapping is not observed in any of the wells studied here. In general many of the agglutinated foraminifers observed in ODP Site 643 seem to range much higher - up into the Miocene - than those from the Halten Bank area. It has also been noted in the Palaeogene of the Labrador Sea and Labrador 'Shelf' (Kaminski *et al.*, 1989a; Gradstein *et al.* 1994) that agglutinated foraminifers disappear much earlier - around the Eocene/Oligocene boundary. The later disappearance of agglutinated foraminifers in the deep sites of the Vøring Slope is probably due to the waters of the Norwegian Sea remaining stratified throughout the Palaeogene and early Neogene with deeper waters being more corrosive (Kaminski *et al.*, 1990).

Osterman & 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

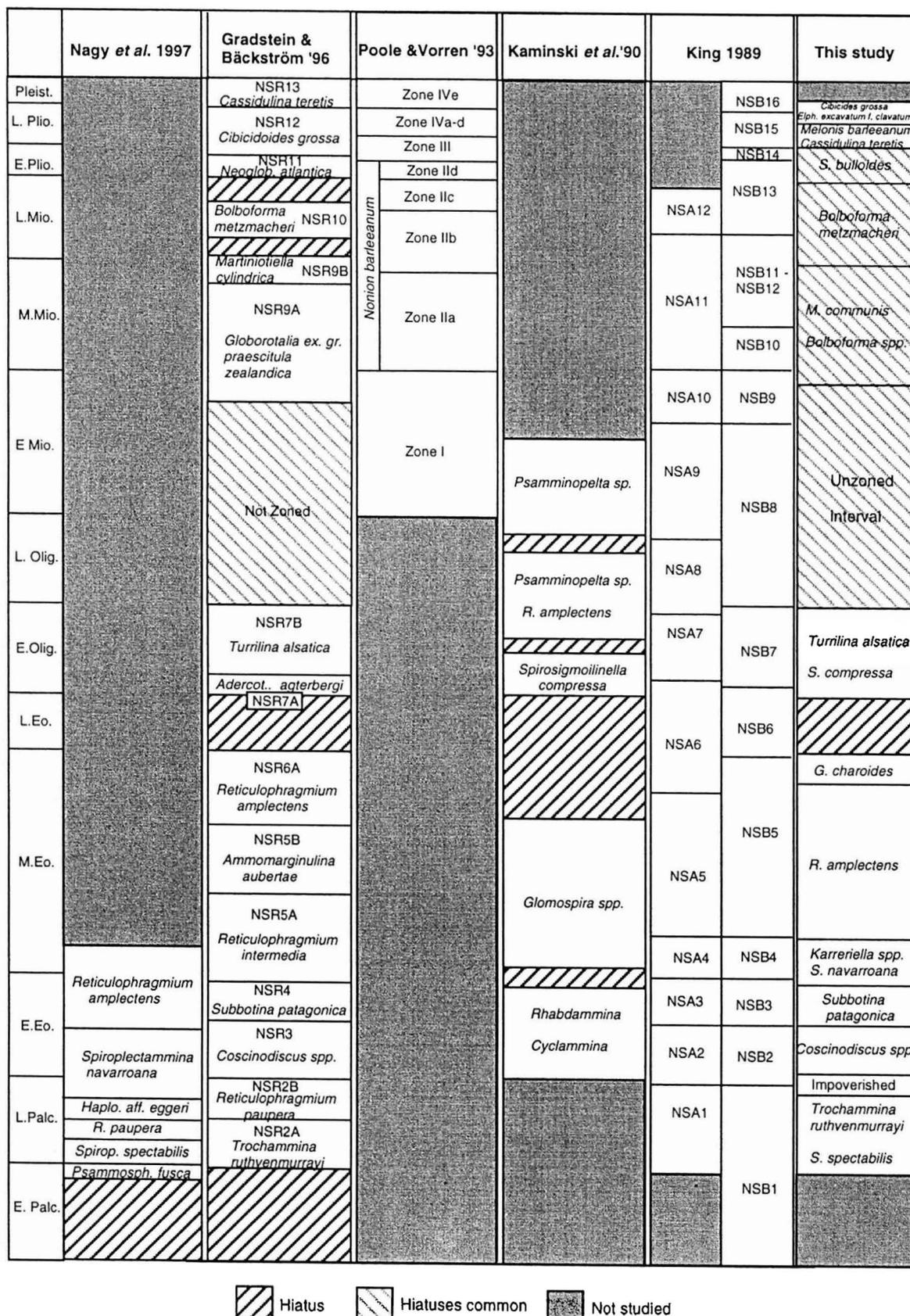


Figure 5. Approximate correlation of Halten Terrace biostratigraphy to other biostratigraphic schemes.

*Reticulophragmium amplexans*. These authors also found that middle-late 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 elsewhere. *Reticulophragmium amplexans* 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 Late Oligocene. Osterman & Spiegler (1996) postulated that a deep-water basin in the Fram Strait area was responsible for the anomalously long ranges of the foraminifers from Site 909 and that this basin remained isolated from the rest of the North Atlantic until the Miocene.

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 Palaeocene and mid- to late Eocene (late mid-Ypresian to late Rupelian) was observed. During the early Eocene (early to mid-Ypresian) assemblages with high numbers of planktic foraminifers were recorded. As in this study the agglutinated assemblages disappeared within the upper middle Eocene to Lower Oligocene section. In contrast to this work they found planktic-rich assemblages in the lower part of the upper Palaeocene, and abundant and diverse calcareous benthic assemblages from the lower Oligocene onwards.

King's (1989) zonal scheme for the North Sea 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 Palaeogene and Lower Neogene so during this time only the NSA zones are applicable.

Kaminski *et al.* (1989a) noted that in the Labrador Sea at ODP Site 647 the Palaeogene 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. This is similar to the findings from the Halten Terrace, although the assemblages at the Halten Terrace 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 (Kaminski *et al.* 1989a).

#### PALAEOENVIRONMENT

Using changes in the foraminiferal assemblages five main changes in palaeoenvironment can be defined.

1. During the late Palaeocene the sites studied probably experienced deep water conditions with

relatively nutrient rich, warm waters. Deposition was below the CCD as witnessed by 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 Palaeocene/Eocene boundary. These probably relate to the opening of the Norwegian-Greenland Sea. Pyritized diatoms are common at the top of the interval. There was subsequently an interval of increased current activity together with some uplift and a deepening of the CCD. Assemblages containing the planktic foraminifer *Subbotina patagonica* are common during this interval. The appearance of subbotinids during the earliest Eocene indicates a position above the CCD, they may also imply a cooling of at least the surface waters as subbotinids are thought to be cool water indicators (Pardo *et al.*, 1997).

3. Purely organically cemented agglutinated assemblages are found in the lower Eocene. 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, waters and a return to more oxygenated conditions below the CCD.

4. The mid-Eocene heralds the start of siliceous sedimentation, increased organic matter accumulation and a deterioration of subsurface oxygen conditions. Assemblages are dominated by *Reticulophragmium amplexans*. 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. In the upper Middle Eocene impoverished foraminiferal assemblages, often with *Glomospira charoides*, are recorded. Siliceous microfossils, especially radiolaria, dominate.

5. During the Oligocene and early Miocene there was a domination by siliceous microfossils. Numerous hiatuses and barren periods indicate an increase in current activity. The very high numbers of radiolarians recorded may point to waters deeper than 150m, (Hull, 1996). Foraminiferal assemblages are impoverished with either mainly agglutinated (Oligocene) or calcareous (Miocene) foraminifers. The appearance of calcareous foraminifers indicates deepening of the CCD and/or shallowing of the sites. The presence of *Turrilina alsatica* may indicate low to intermediate bottom water oxygen conditions (Kaiho, 1991).

#### SUMMARY

1. A total of nine assemblage zones for the Palaeogene were identified using a combination of foraminifers (agglutinated and calcareous) and other microfossils such as diatoms and radiolaria. The biostratigraphy created has been correlated

with other schemes from the same or adjacent areas. Biostratigraphical schemes from the Norwegian Sea were found to be most similar, while those from the North Sea, although applicable 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 Palaeogene 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 good general agreement.

2. The Lower Palaeogene samples (Upper Palaeocene to mid-Eocene) are dominated by agglutinated foraminifers. Seven assemblage zones were identified of which five were characterised by agglutinated foraminifers, one by planktic foraminifers and one by diatoms.

3. In the Upper Oligocene to Middle Miocene foraminifers (agglutinated and calcareous) can only rarely be used for biostratigraphic purposes. Siliceous microfossils (diatoms and radiolaria) dominate. It is possible to utilise their presence in this interval together with the appearance of rare foraminifers for biostratigraphic purposes. One zone was identified which was characterised by the presence of a few planktic foraminifers together with siliceous microfossils. The section from the Upper Oligocene to the Lower Miocene is not characterised by any foraminifers or useful microfossils and was left unzoned.

4. Although agglutinated foraminifers can often be relatively long ranging and have a high tolerance to fluctuating conditions, changes in assemblage composition can be helpful in inferring palaeoenvironments. Using evidence from changes in foraminiferal morphogroups and in foraminiferal and other microfossil distribution patterns, a succession of palaeoenvironments on the Halten Terrace can be outlined. The foraminiferal patterns are influenced by tectonic movements, sedimentation rates, circulation patterns and changes in organic flux.

5. During the late Palaeocene the sites studied experienced deep water conditions below the CCD with relatively nutrient rich, warm waters with medium strength bottom currents. The opening of the Norwegian-Greenland Sea led 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.*, 1997 and references therein). The early Eocene is characterised by a return to deeper sub-CCD conditions with a reduced nutrient input. In the mid-Eocene siliceous sedimentation and increased organic matter accumulation led to more corrosive bottom waters and a decrease in subsurface oxygen conditions, which in turn probably caused the extinction of many foraminifers leaving only

impoverished agglutinated assemblages that were dominated by siliceous microfossils. The Oligocene and early Miocene were times of increased current activity, high biosiliceous input and falling sea levels. Assemblages are extremely impoverished to barren, although the beginning of improved conditions is seen in the Miocene with the first appearance of calcareous benthics.

#### TAXONOMY

The generic classification follows largely the scheme of Loeblich & Tappan (1987). Where appropriate, emendations from Jones (1994), Gradstein & Kaminski (1989) and Kaminski *et al.* (1993) were used. Taxa are presented alphabetically. Only the most frequent taxa are mentioned below. 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.

#### *Adercotryma agterbergi* Gradstein & Kaminski, 1989

Plate 4, Fig. 1

*Adercotryma agterbergi* Gradstein & Kaminski. - Kaminski *et al.*, 1990, p. 367, pl. 4, fig. 5a-b.

*Adercotryma agterbergi* Gradstein & Kaminski. - Gradstein *et al.*, 1994, pl. 7, figs 12-14. pl. 8, figs 1-5.

#### *Ammodiscus cretaceus* (Reuss, 1845)

Plate 3, Fig. 1

*Ammodiscus cretaceus* Reuss. - Labude, 1984, p. 69, pl. 1, fig. 7.

*Ammodiscus cretaceus* Reuss. - Kaminski *et al.*, 1988, p. 213, pl. 3, fig. 7.

*Ammodiscus cretaceus* Reuss. - Kuhnt, 1990, p. 313, pl. 1, figs 2-3.

*Ammodiscus cretaceus* Reuss. - Charnock & Jones, 1990, p. 154, pl. 2, figs 1-3; pl. 14, fig. 3.

*Ammodiscus cretaceus* Reuss. - Morlotti & Kuhnt, 1992, p. 221, pl. 1, figs 1-2.

#### *Ammodiscus pennyi* Cushman & Jarvis, 1928

Plate 3, Fig. 3

*Ammodiscus pennyi* Cushman & Jarvis. - Kaminski *et al.*, 1988, pp. 184-185, pl. 3, figs 9-10.

*Ammodiscus pennyi* Cushman & Jarvis. - Kuhnt, 1990, p. 313, pl. 1, fig. 6.

#### *Ammodiscus peruvianus* Berry, 1928

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

*Ammodiscus peruvianus* Berry. - Morlotti & Kuhnt, 1992, p. 221, pl. 1, fig. 4.

#### *Ammodiscus tenuissimus* Grzybowski, 1898

Plate 3, Fig. 2

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

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

#### *Ammomarginulina aubertae* Gradstein & Kaminski, 1989

Plate 3, Fig. 12

- Ammomarginulina aubertae* Gradstein & Kaminski. - Gradstein & Kaminski, 1989, p. 74, pl. 3, figs 1-8, pl. 4, figs 1-3, text-fig. 2.  
*Ammomarginulina aubertae* Gradstein & Kaminski. - Charnock & Jones, 1990, p. 179, pl. 9, figs 6-8; pl. 20, fig. 7.  
*Ammomarginulina aubertae* Gradstein & Kaminski. - Gradstein *et al.*, 1994, pl. 6, figs 15-22.

***Ammosphaeroidina pseudopauciloculata* (Mjatliuk, 1966)**

- Ammosphaeroidina pseudopauciloculata* (Mjatliuk). - Kaminski *et al.*, 1988, p. 193, pl. 8, figs 3-5.  
*Ammosphaeroidina pseudopauciloculata* (Mjatliuk). - Kuhnt, 1990, p. 321, pl. 5, fig. 1.  
*Ammosphaeroidina pseudopauciloculata* (Mjatliuk). - Gradstein *et al.*, 1994, pl. 3, figs 1-7.

***Bathysiphon annulatus* (Andreae, 1890)**

- Bathysiphon annulatus* (Andreae). - Kaminski *et al.*, 1988, p. 184, pl. 1, figs 16-17.  
*Bathysiphon annulatus* (Andreae). - Charnock & Jones, 1990, p. 149, pl. 1, fig. 30; pl. 13, fig. 10.

***Bigenerina* sp. 1 Charnock & Jones, 1990**

Plate 1, Fig. 4

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

***Budashevaella multicamerata* Voloshinova, 1961**

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

***Buzasina galeata* (Brady, 1881)**

- Buzasina galeata* (Brady). - Charnock & Jones, 1990, p. 166, pl. 5, fig. 1; pl. 16, fig. 1.  
*Buzasina galeata* (Brady). - Jones, 1994, p. 45, pl. 40, figs 19-23.

***Conglophragmium coronatum* (Brady, 1879)**

Plate 4, Fig. 9

- Conglophragmium coronatum* (Brady). - Charnock & Jones, 1990, p. 167, pl. 5, figs 2-3; pl. 16, fig. 2.  
*Conglophragmium coronatum* (Brady). - Jones, 1994, p. 45, pl. 40, figs 8-12.

***Cribrostomoides subglobosus* forma *subglobosus***

(Cushman, 1910), emend. Jones *et al.*, (1993)

- Cribrostomoides subglobosus* forma *subglobosus* (Cushman), emend. Jones *et al.*, - Jones *et al.*, 1993, pp. 181-193, pl. 3, figs 1-7.  
*Cribrostomoides subglobosus* forma *subglobosus* Cushman), emend. Jones *et al.*, - Bender, 1995, p. 42, pl. 5, fig. 2.

***Cribrostomoides* sp. 1**

Plate 3, Figs 10, 11

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

***Cyclammina placenta* (Reuss, 1851)**

Plate 2, Fig. 3

- Cyclammina* (*Cyclammina*) *placenta* (Reuss). - Charnock & Jones, 1990, p. 175, pl. 7, figs 5-12, pl. 18, fig. 4.  
 "Cyclammina" *placenta* (Reuss). - Kaminski *et al.*, 1990, p. 369, pl. 6, fig. 2a-b.  
*Cyclammina placenta* (Reuss). - Gradstein *et al.*, 1994, pl. 6, fig. 7-11.

***Cyclammina rotundidorsata* (Hantken, 1875)**

- Cyclammina* (*Reticulophragmium*) *rotundidorsata* (Hantken). - Charnock & Jones, 1990, p. 176, pl. 7, figs 13-15; pl. 19, fig. 1.  
*Cyclammina rotundidorsata* (Hantken). - Jones, 1994, p. 43, pl. 37, figs 17-19.  
*Cyclammina rotundidorsata* (Hantken). - Gradstein *et al.*, 1994, pl. 6, figs 13-14.

***Cystammina pauciloculata* (Brady, 1879)**

Plate 3, Figs 5, 7, 8

- Cystammina pauciloculata* (Brady). - Schröder, 1986, p. 54, pl. 18, figs 14, 15.  
*Cystammina pauciloculata* (Brady). - Charnock & Jones, 1990, pp. 168-169, pl. 5, fig. 7.  
*Cystammina pauciloculata* (Brady). - Jones, 1994, p. 45, pl. 41, fig. 1.  
*Cystammina pauciloculata* (Brady). - Gradstein *et al.*, 1994, pl. 3, figs 8-12.

The assemblages studied may also contain specimens of *Cystammina sveni* Gradstein & Kaminski (1997), (Gradstein, pers. comm., 1997).

***Evolutinella* sp. 1**

Plate 2, Fig. 10

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

***Glomospira charoides* (Jones & Parker, 1860)**

Plate 3, Figs 4, 9

- Glomospira charoides* (Jones & Parker). - Kaminski *et al.*, 1988, p. 185, pl. 3, figs 14-15.  
*Glomospira charoides* (Jones & Parker). - King, 1989, p. 455, pl. 9.1, fig. 17.  
*Glomospira charoides* (Jones & Parker). - Kuhnt, 1990, p. 313, pl. 1, fig. 11.  
*Glomospira charoides* (Jones & Parker). - Morlotti & Kuhnt, 1992, p. 222, pl. 1, figs 7-8.

***Glomospira diffundens* (Cushman & Renz, 1946)**

- Glomospira diffundens* (Cushman & Renz). - Kaminski *et al.*, 1988, p. 185, pl. 3, figs 18-19.

***Glomospira glomerata* (Grzybowski, 1898)**

Plate 3, Fig. 6

- Glomospira glomerata* (Grzybowski). - Kaminski *et al.*, 1988, p. 185, pl. 3, fig. 16.  
*Glomospira glomerata* (Grzybowski). - Charnock & Jones, 1990, p. 156, pl. 2, fig. 11.  
*Glomospira glomerata* (Grzybowski). - Kaminski & Geroch, 1993, p. 257, pl. 6, figs 9-12.  
*Glomospira glomerata* (Grzybowski). - Kaminski *et al.*, 1996, pl. 1, fig. 13.

***Glomospira gordialis* (Jones & Parker, 1860)**

- Glomospira gordialis* (Jones & Parker). - Kaminski *et al.*, 1988, p. 213, pl. 3, fig. 17.  
*Glomospira gordialis* (Jones & Parker). - Kuhnt, 1990, p. 313, pl. 1, figs 9-10.  
*Glomospira gordialis* (Jones & Parker). - Charnock & Jones, 1990, p. 156, pl. 2, fig. 12; pl. 14, fig. 9.  
*Glomospira gordialis* (Jones & Parker). - Morlotti & Kuhnt, 1992, p. 222, pl. 1, fig. 9.

***Glomospira irregularis* (Grzybowski, 1898)**

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

- Glomospira irregularis* (Grzybowski). - Kuhnt, 1990, p. 313, pl. 1, fig. 12.  
*Glomospira irregularis* (Grzybowski). - Charnock & Jones, 1990, p. 157, pl. 2, fig. 14; pl. 14, fig. 11.  
*Glomospira irregularis* (Grzybowski). - Morlotti & Kuhnt, 1992, p. 222, pl. 1, fig. 12.

***Glomospira serpens* (Grzybowski, 1898)**

- Glomospira serpens* (Grzybowski). - Kaminski *et al.*, 1988, p. 185, pl. 3, figs 22-23.  
*Glomospira serpens* (Grzybowski). - Kuhnt, 1990, p. 313, pl. 1, fig. 4.  
*Glomospira serpens* (Grzybowski). - Kaminski *et al.*, 1996, pl. 1, fig. 15.

***Haplophragmoides cf. concavus* (Chapman, 1892)**

- Haplophragmoides cf. concavus* (Chapman). - Kuhnt, 1990, p. 312, pl. 4, fig. 13.

***Haplophragmoides horridus* (Grzybowski, 1901)**

- Haplophragmoides horridus* (Grzybowski). - Kaminski *et al.*, 1988, p. 189, pl. 5, fig. 11a-b.  
*Haplophragmoides horridus* (Grzybowski). - Charnock & Jones, 1990, p. 170, pl. 5, figs 15-16; pl. 16, fig. 9.

***Haplophragmoides kirki* Wickenden, 1932**

Plate 2, Fig. 9

- Haplophragmoides kirki* Wickenden. - King, 1989, p. 455, pl. 9.1, fig. 19.  
*Haplophragmoides kirki* Wickenden. - Charnock & Jones, 1990, p. 170, pl. 5, figs 17-18; pl. 16, fig. 10.  
*Haplophragmoides kirki* Wickenden. - Gradstein *et al.*, 1994, pl. 6, figs 1-6.

***Haplophragmoides cf. kirki* Wickenden, 1932**

Plate 2, Fig. 6

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

Coarser grained and somewhat larger than *H. kirki*

***Haplophragmoides porrectus* Maslakova, 1955**

Plate 2, Fig. 8

- Haplophragmoides porrectus* Maslakova. - Kaminski *et al.*, 1988, p. 189, pl. 5, figs 7-8.  
*Haplophragmoides porrectus* Maslakova. - Charnock & Jones, 1990, p. 171, pl. 5, fig. 19.

***Haplophragmoides stomatus* (Grzybowski, 1898)**

Plate 2, Fig. 7

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

***Haplophragmoides suborbicularis* (Grzybowski, 1896)**

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

***Haplophragmoides walteri* (Grzybowski, 1898)**

Plate 2, Fig. 5

- Haplophragmoides walteri* (Grzybowski). - Kaminski *et al.*, 1988, p. 190, pl. 5, figs 14-15.  
*Haplophragmoides walteri* (Grzybowski). - Charnock & Jones, 1990, p. 171, pl. 6, figs 3-4.  
*Haplophragmoides walteri* (Grzybowski). - Kuhnt, 1990, p. 314, pl. 4, figs 10-12.  
*Haplophragmoides walteri* (Grzybowski). - Gradstein *et al.*, 1994, pl. 7, figs 1-5.

***Haplophragmoides walteri excavatus* Cushman &**

Waters, 1927

- Haplophragmoides walteri excavatus* Cushman & Waters. - Kaminski *et al.*, 1990, p. 368, pl. 5, fig. 6a-b.  
*Haplophragmoides walteri excavatus* Cushman & Waters. - Gradstein *et al.*, 1994, pl. 7, figs 6-9.

***Haplophragmoides* sp. 2**

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

***Kalamopsis grzybowskii* (Dylążanka, 1923)**

- Kalamopsis grzybowskii* (Dylążanka). - Kaminski *et al.*, 1988, p. 187, pl. 1, figs 18-20.  
*Kalamopsis grzybowskii* (Dylążanka). - Charnock & Jones, 1990, p. 151, pl. 1, figs 21-22; pl. 13, fig. 21.  
*Kalamopsis grzybowskii* (Dylążanka). - Kaminski & Geroch, 1993, p. 281, pl. 17, figs 5a-8.

***Karrieriella chapapotensis* (Cole, 1928)**

- Karrieriella chapapotensis* (Cole). - Kaminski *et al.*, 1990, p. 370, pl. 8, fig. 8.

***Karrieriella horrida* Mjatliuk, 1970**

Plate 1, Fig. 8

- Karrieriella horrida* Mjatliuk. - Kaminski *et al.*, 1988, p. 196, pl. 9, figs 19-20.  
*Karrieriella horrida* Mjatliuk. - Kaminski *et al.*, 1990, p. 370, pl. 8, figs 7-8.  
*Karrierulina horrida* (Mjatliuk). - Kaminski & Geroch, 1993, p. 269, pl. 13, figs 14a-15b.

***Karrierulina coniformis* (Grzybowski, 1898)**

- Karrieriella coniformis* (Grzybowski). - Kaminski *et al.*, 1988, p. 195, pl. 9, figs 15-16.  
*Karrierulina coniformis* (Grzybowski). - Charnock & Jones, 1990, p. 195, pl. 25, fig. 9.  
*Karrierulina coniformis* (Grzybowski). - Kaminski & Geroch, 1993, pp. 269-270, pl. 13, figs 1-4.

***Karrierulina conversa* (Grzybowski, 1901)**

Plate 1, Figs 6, 7

- Karrieriella conversa* (Grzybowski). - Kaminski *et al.*, 1988, p. 196, pl. 9, figs 17-18b.  
*Karrierulina conversa* (Grzybowski). - King, 1989, p. 456, pl. 9.2, figs 23, 24.  
*Karrieriella conversa* (Grzybowski). - Kaminski, 1990, p. 370, pl. 8, fig. 5.  
*Karrierulina conversa* (Grzybowski). - Charnock & Jones, 1990, pp. 195-196, pl. 12, fig. 19.  
*Karrierulina conversa* (Grzybowski). - Morlotti & Kuhnt, 1992, p. 222, pl. 4, fig. 15.

***Martinottiella communis* (d'Orbigny, 1846)**

Plate 1, Fig. 9

- Martinottiella communis* (d'Orbigny). - Schröder, 1986, p. 56, pl. 22, fig. 11.  
*Martinottiella communis* (d'Orbigny). - King, 1989, p. 456, pl. 9.2, figs 4, 5.  
*Martinottiella communis* (d'Orbigny). - Bender, 1995, p. 46, pl. 6, fig. 16.

***Paratrochammina challengerii* Brönnimann & Whittaker, 1988**

- Trochammina cf. globigeriniformis* (Parker & Jones). - Schröder, 1986, pp. 52-53, pl. 19, figs 5-8.  
*Trochaminopsis challengerii* (Brönnimann & Whittaker). - Charnock & Jones, 1990, p. 189, pl. 11, figs 7-10, pl. 22, fig. 6.

*Paratrochammina challengerii* Brönnimann & Whittaker. - Jones, 1994, pp. 41-42, pl. 35, fig. 10.

***Recurvoides* ex. gr. *gerochi*** Pflaumann, 1964  
Plate 4, Fig. 6

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

***Recurvoides* ex. gr. *turbinatus*** (Brady, 1881)  
Plate 2, Fig. 12

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

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

***Recurvoides* sp. 2**  
Plate 4, Fig. 2

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

***Recurvoides* sp. 3**  
Plate 4, Fig. 3

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

***Reticulophragmium amplexens*** (Grzybowski, 1898)  
Plate 2, Figs 1, 2

*Reticulophragmium amplexens* (Grzybowski). - King, 1989, p. 458, pl. 9.2, figs 16-18.

*Reticulophragmium amplexens* (Grzybowski). - Kaminski *et al.*, 1990, p. 369, pl. 6, fig. 4a-b.

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

*Reticulophragmium amplexens* (Grzybowski). - Kaminski & Geroch, 1993, p. 266, pl. 11, figs 5-7c.

*Reticulophragmium amplexens* (Grzybowski). - Gradstein *et al.*, 1994, pl. 4, figs 1-5, pl. 5, figs 1-10.

***Reticulophragmium intermedia*** (Mjatluk, 1970)  
Plate 2, Fig. 4

*Cyclammina?* *intermedia* Mjatluk, 1970, p. 89, pl. 21, fig 6, pl. 28, fig. 1a-c.

***Reticulophragmoides jarvisi*** (Thalman, 1932),  
emend Gradstein & Kaminski, 1989

*Reticulophragmoides jarvisi* (Thalman), emend Gradstein & Kaminski, 1989, pp. 81, 83, pl. 7, figs 1-8, text-fig. 4.

*Reticulophragmoides jarvisi* (Thalman), emend Gradstein & Kaminski. - Charnock & Jones, 1990, p. 177, pl. 8, figs 12-13, pl. 19, fig. 4.

*Reticulophragmoides jarvisi* (Thalman), emend Gradstein & Kaminski. - Gradstein *et al.*, 1994, pl. 7, figs 10-11, pl. 11, fig. 6.

***Rhabdammina abysorum*** Sars, In Carpenter, 1869  
Plate 1, Fig. 11

*Rhabdammina abysorum* Sars, In Carpenter. - Charnock & Jones, 1990, p. 152, pl. 1, figs 23-24, pl. 2, fig. 9, pl. 13, fig. 22.

***Rhabdammina excelsa*** (Grzybowski, 1898)

*Rhizammina indivisa* Brady. - Kaminski *et al.*, 1988, p. 183,

pl. 1, figs 10-13.

*Rhabdammina excelsa* (Grzybowski). - Charnock & Jones, 1990, p. 152, pl. 1, figs 26-27, pl. 13, fig. 24.

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

*Rhizammina indivisa* Brady. - Morlotti & Kuhnt, 1992, p. 223, pl. 2, fig. 4.

***Rzehakina minima*** (Cushman & Renz, 1946)  
Plate 1, Fig. 12

*Rzehakina minima* (Cushman & Renz). - Kaminski *et al.*, 1988, p. 186, pl. 7, figs 8-9.

*Rzehakina minima* (Cushman & Renz). - Jones, 1988, p. 148, pl. 2, fig. 2.

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

*Rzehakina minima* (Cushman & Renz). - Gradstein *et al.*, 1994, pl. 9, figs 18-20.

***Rzehakina epigona*** (Rzehak, 1895)  
Plate 1, Fig. 14

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

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

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

***Saccammina placenta*** (Grzybowski, 1898)

*Saccammina placenta* (Grzybowski). - Kaminski *et al.*, 1988, p. 183, pl. 2, fig. 9.

*Saccammina placenta* (Grzybowski). - Kuhnt, 1990, p. 325, pl. 2, fig. 1.

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

***Sigmoilopsis schlumbergeri*** (Silvestri, 1904)

*Sigmoilopsis schlumbergeri* (Silvestri). - Schröder, 1986, p. 56, pl. 21, fig. 9.

*Sigmoilopsis schlumbergeri* (Silvestri). - King, 1989, p. 462, pl. 9.3, figs 10, 11.

*Sigmoilopsis schlumbergeri* (Silvestri). - Bender, 1995, p. 52, pl. 7, fig. 18, pl. 12, fig. 7.

***Spiroplectammina deperdita*** (D'Orbigny, 1846)

*Spiroplectammina* (*Spiroplectinella*) *deperdita* (D'Orbigny). - Charnock & Jones, 1990, p. 182, pl. 9, fig. 14; pl. 21, fig. 4.

***Spiroplectammina navarroana*** Cushman, 1932,  
emend Gradstein & Kaminski, 1989  
Plate 1, Fig. 5

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

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

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

*Spiroplectammina navarroana* Cushman, emend Gradstein & Kaminski. - Gradstein *et al.*, 1994, pl. 1, fig. 12a,b, pl. 11, figs 11-12.

***Spiroplectammina spectabilis*** (Grzybowski, 1898)  
Plate 1, Figs 1-3

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

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

*Spiroplectammina spectabilis* (Grzybowski). - Kaminski & Geroch, 1993, pp. 267-268, pl. 12, figs 4a-5c.

***Spirosigmoilinella compressa*** Matsunaga, 1955  
Plate 1, Figs 13, 15

*Spirosigmoilinella compressa* Matsunaga. - Charnock & Jones, 1990, p. 159, pl. 3, figs 5-6; pl. 14, fig. 16.  
*Spirosigmoilinella compressa* Matsunaga. - Kaminski *et al.*, 1990, p. 367, pl. 4, figs 1-2.

***Subreophax scalaris*** (Grzybowski, 1896)

*Subreophax scalaris* (Grzybowski). - Kaminski *et al.*, 1988, p. 187, pl. 2, figs 16-17.  
*Subreophax scalaris* (Grzybowski). - Kuhnt, 1990, p. 326, pl. 3, figs 4-5.  
*Subreophax scalaris* (Grzybowski). - Morlotti & Kuhnt, 1992, p. 223, pl. 3, fig. 5.

***Trochammina altiformis*** (Cushman & Renz, 1946)  
Plate 2, Fig. 11

*Trochammina altiformis* (Cushman & Renz). - Kaminski *et al.*, 1988, p. 193, pl. 8, figs 1a-2b.

***Trochammina deformis*** Grzybowski, 1898

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

***Trochammina ruthvenmurrayi*** Cushman & Renz,  
1946  
Plate 4, Figs 10, 12

*Trochammina ruthvenmurrayi* Cushman & Renz. - Kaminski *et al.*, 1988, p. 193, pl. 8, fig. 6a-c.  
*Trochammina ruthvenmurrayi* Cushman & Renz. - King, 1989, p. 460, pl. 9.3, figs 3,4.  
*Trochammina (Ammonita) ruthvenmurrayi* Cushman & Renz. - Charnock & Jones, 1990, p. 186, pl. 10, figs 4-9; pl. 22, fig. 2.

***Trochammina subvesicularis*** Hanzlíková, in  
Homola & Hanzlíková, 1955  
Plate 4, Fig. 11

*Trochammina (Insculptarenula) subvesicularis* Hanzlíková, in Homola & Hanzlíková. - Charnock & Jones, 1990, p. 187, pl. 10, figs 10-12; pl. 22, fig. 3.  
*Trochammina cf. subvesicularis* Hanzlíková, in Homola & Hanzlíková. - Gradstein *et al.*, 1994, pl. 1, fig 4-5.

The assemblages studied may also contain specimens of *Ammonita ingerlisae* Gradstein & Kaminski (1997), (F. Gradstein, pers. comm., 1997).

***Trochammina* sp. 5**  
Plate 4, Figs 4-5

Small, plano-convex with 7 chambers in final whorl. Sutures are curved and slightly depressed. Wall is finely grained. Probably *Trochammina* sp. 2 Charnock & Jones 1990, p. 188, pl. 11, figs 11-12. pl. 23. fig. 1. (M. Charnock, pers. comm., 1998)

***Trochamminoides dubius*** (Grzybowski, 1898)  
Plate 4, Fig. 7

*Trochamminoides dubius* (Grzybowski). - Kaminski *et al.*, 1988, p. 191, pl. 4, figs 16-17.  
*Trochamminoides dubius* (Grzybowski). - Kuhnt, 1990, p. 326, pl. 5, fig. 9.  
*Trochamminoides dubius* (Grzybowski). - Kaminski *et al.*, 1996, pl. 3, figs 1-4.

***Trochamminoides irregularis*** (White, 1928)  
Plate 4, Fig. 8

*Trochamminoides irregularis* (White). - Kaminski *et al.*, 1988, p. 191, pl. 4, fig. 18.  
*Trochamminoides irregularis* (White). - Kuhnt, 1990, p. 320, pl. 5, fig. 10.

***Trochamminoides proteus*** (Karrer, 1866)

*Trochamminoides proteus* (Karrer). - Kaminski *et al.*, 1988, p. 192, pl. 4, fig. 20.  
*Trochamminoides proteus* (Karrer). - Kuhnt, 1990, p. 326, pl. 5, fig. 10.  
*Trochamminoides proteus* (Karrer). - Charnock & Jones, 1990, p. 161, pl. 3, fig. 12; pl. 15, fig. 2.

***Trochamminoides subcoronatus*** (Grzybowski, 1896)

*Trochamminoides subcoronatus* (Grzybowski). - Kaminski *et al.*, 1988, p. 192, pl. 4, fig. 20.  
*Trochamminoides subcoronatus* (Grzybowski). - Morlotti & Kuhnt, 1992, p. 223, pl. 3, fig. 13.

***Trochamminopsis pseudovesicularis***  
(Krashennikov, 1974)

*Trochamminopsis pseudovesicularis* (Krashennikov). - Charnock & Jones, 1990, p. 189, pl. 22, fig. 7.

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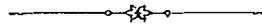
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### EXPLANATIONS TO PLATES

**PLATE 1.** 1. *Spiroplectammina spectabilis*, Well 6406/11-1, 1890m, x38. 2. *Spiroplectammina spectabilis*, Well 6407/7-2, 1970m, x56. 3. *Spiroplectammina spectabilis*, Well 6406/11-1, 2330m, x42. 4. *Bigennerina* sp. 1, Well 6407/7-2, 1950m, x56. 5. *Spiroplectammina navarroana*, Well 6406/11-1, 2150m, x46. 6. *Karrerulina conversa*, Well 6407/7-2, 1760m, x42. 7. *Karrerulina conversa*, Well 6406/11-1, 2350m, x38. 8. *Karrieriella horrida*, Well 6407/7-2, 1760m, x86. 9. *Martinottiella communis*, Well 6406/8-1, 1680m, x23. 10. *Bathysiphon* sp., Well 6406/8-1, 2760m, x29. 11. *Rhabdammina abyssorum*, Well 6406/11-1, 2350m, x60. 12. *Rzehakina minima*, Well 6406/11-1, 2260m, x69. 13. *Spirosigmoilinella compressa*, Well 6407/7-2, 1240m, x58. 14. *Rzehakina epigona*, Well 6406/8-1, 2710m, x75. 15. *Spirosigmoilinella compressa*, Well 6406/8-1, 1980m, x71. 16. ?*Turrilina alsatica*, Well 6406/11-1, 1480m, x175.

**PLATE 2.** 1. *Reticulophragmium amplectens*, Well 6407/7-2, 1760m, x48. 2. *Reticulophragmium amplectens*, Well 6407/7-2, 1870m, x60. 3. *Cyclammmina placenta*, Well 6406/11-1, 1760m, x15. 4. *Reticulophragmium intermedia*, Well 6407/7-2, 1570m, x86. 5. *Haplophragmoides walteri*, Well 6406/8-1, 2710m, x112. 6. *Haplophragmoides* cf. *kirki*, Well 6407/9-3, 1300m, x110. 7. *Haplophragmoides stomatus*, Well 6407/7-2, 1760m, x83. 8. *Haplophragmoides porrectus*, Well 6407/7-2, 1710m, x122. 9. *Haplophragmoides kirki*, Well 6406/11-1, 2280m, x116. 10. *Haplophragmoides* sp. 2, Well 6407/7-2, 1670m, x79. 11. *Trochammina altiformis*, Well 6407/7-2, 1730m, x58. 12. *Recurvoides* ex gr. *turbinatus*, Well 6407/7-2, 1910m, x64.

**PLATE 3.** 1. *Ammodiscus cretaceus*, Well 6407/7-2, 1950m, x49. 2. *Ammodiscus tenuissimus*, Well 6407/7-2, 1710m, x150. 3. *Ammodiscus pennyi*, Well 6407/7-2, 1720m, x60. 4. *Glomospira charoides*, Well 6407/9-3, 960m, x98. 5. *Cystammina pauciloculata/C. sveni*, Well 6407/7-2, 1720m, x90. 6. *Glomospira glomerata*, Well 6406/8-1, 2080m, x27. 7. *Cystammina pauciloculata/C. sveni*, Well 6407/7-2, 1760m, x86. 8. *Cystammina pauciloculata/C. sveni*, Well 6407/7-2, 1760m, x75. 9. *Glomospira charoides*, Well 6407/9-3, 960m, x120. 10. *Cribrostomoides* sp. 1, Well 6407/7-2, 1670m, x144. 11. *Cribrostomoides* sp. 1, Well 6407/7-2, 1670m, x121. 12. *Ammomarginulina aubertae*, Well 6407/7-2, 1670m, x95.

**PLATE 4.** 1. *Adercotryma agterbergi*, Well 6407/7-2, 1650m, x64. 2. *Recurvoides* sp. 2, Well 6407/7-2, 1280m, x131. 3. *Recurvoides* sp. 3, Well 6407/7-2, 1930m, x45. 4. *Trochammina* sp. 5, Well 6406/8-1, 2480m, x131. 5. *Trochammina* sp. 5, Well 6406/8-1, 2480m, x116. 6. *Recurvoides* ex gr. *gerochi*, Well 6407/7-2, 1980m, x83. 7. *Trochamminoides dubius*, Well 6407/9-3, 1280m, x71. 8. *Trochamminoides irregularis*, Well 6407/9-3, 1410m, x50. 9. *Conglophragmium coronatum*, Well 6407/7-2, 1740m, x27. 10. *Trochammina ruthvenmurrayi*, Well 6407/9-3, 1440m, x46. 11. *Trochammina subvesicularis*, Well 6407/7-2, 1910m, x92. 12. *Trochammina ruthvenmurrayi*, Well 6406/11-1, 2310m, x75.

Plate 1

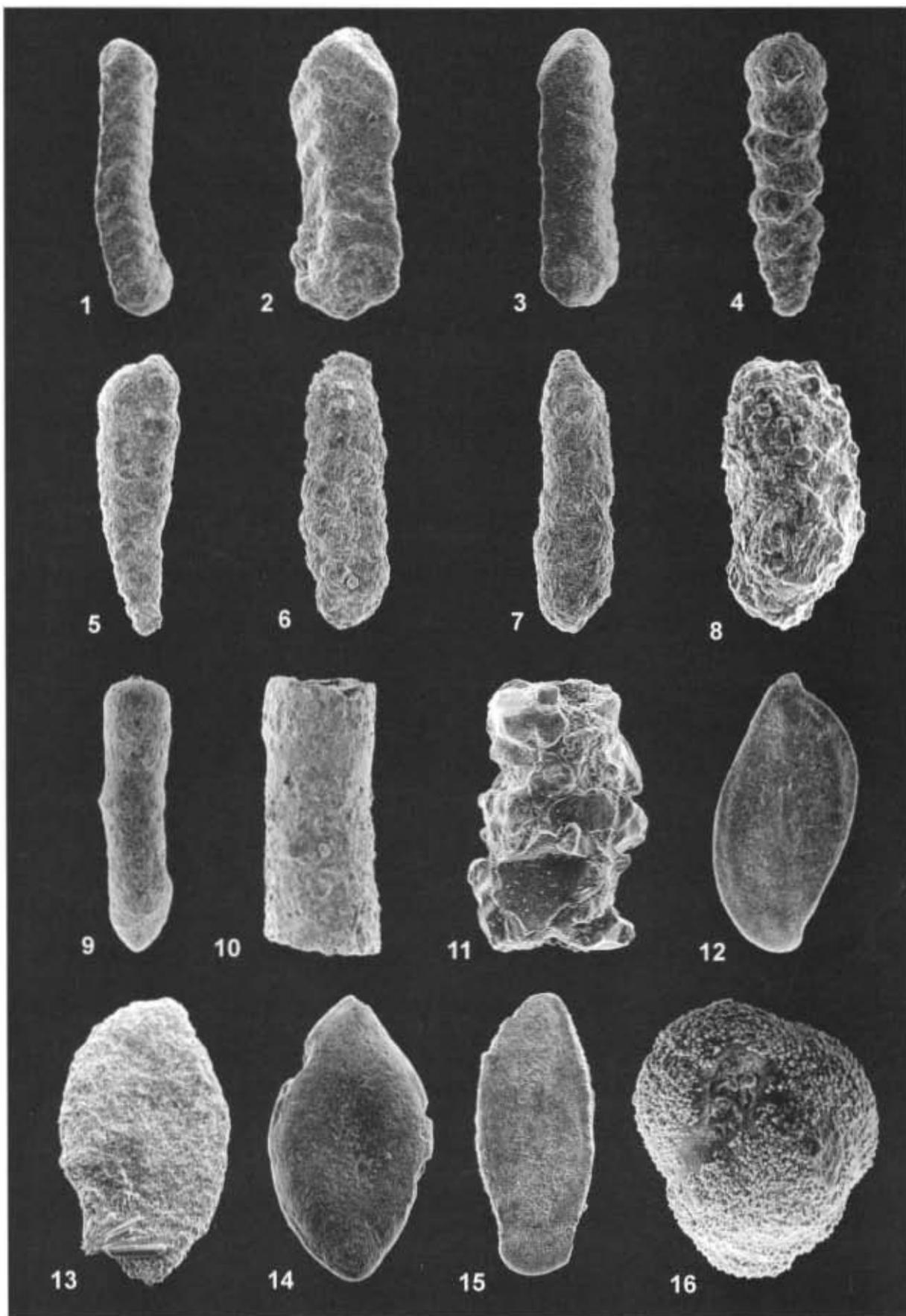
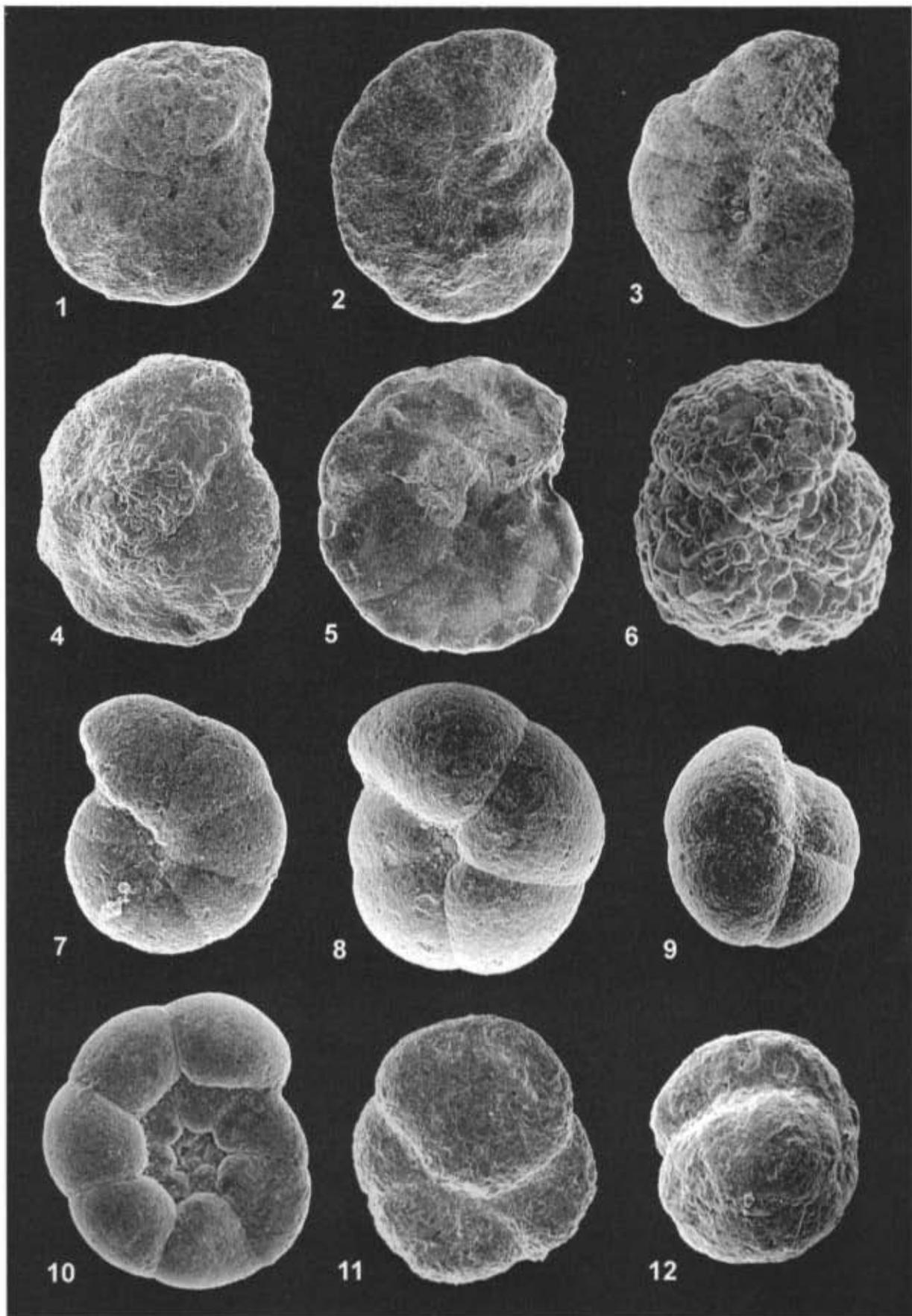


Plate 2



## Plate 3

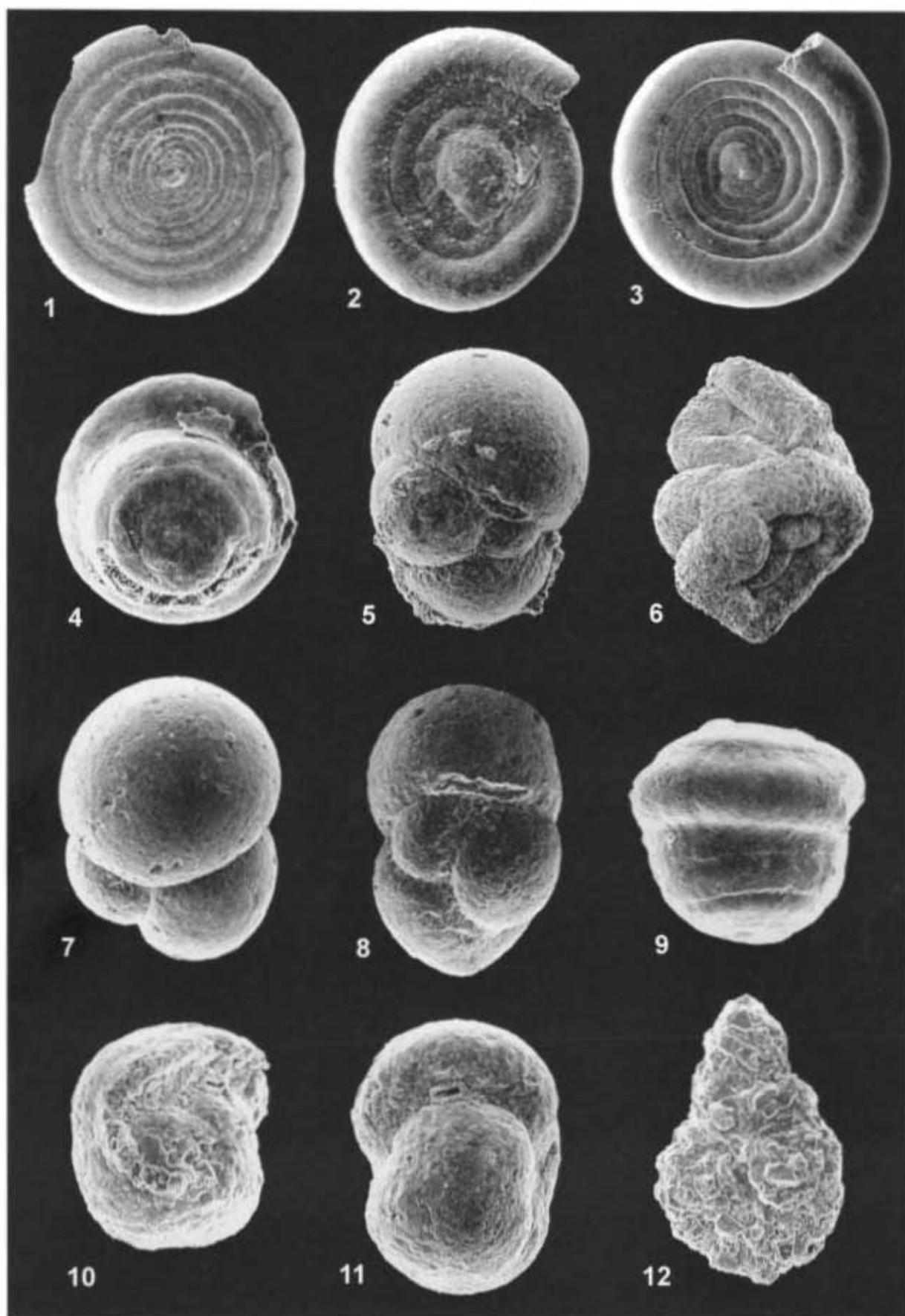


Plate 4

